AL/EQ-TR-1993-0009
Vol II of V

ARMSTRONG LABORATORY

AIR FORCE SITE CHARACTERIZATION AND ANALYSIS PENETROMETER SYSTEM (AFSCAPS): LASER-INDUCED FLUORESCENCE CONE PENETROMETER - TINKER AFB SITE CHARACTERIZATION (VOL II OF V)

James D. Shinn, Wesley L. Bratton

Applied Research Associates, Inc.
RFD #1, Box 120-A, Waterman Road
South Royalton, VT 05068

ENVIRONICS DIRECTORATE
139 Barnes Drive, Suite 2
Tyndall AFB FL 32403-5323

December 1994

Final Technical Report for Period March 1992 - November 1992

Approved for public release; distribution unlimited.

AIR FORCE MATERIEL COMMAND
TYNDALL AIR FORCE BASE, FLORIDA 32403-5323

NOTICES

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any employees, nor any of their contractors, subcontractors, or their employees, make any warranty, expressed or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency , contractor, or subcontractor thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency , contractor, or subcontractor thereof.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder or nay other person or corporation; or as conveying any rights or permission to manufacture, use , or sell any patented invention that may in any way be related thereto.

The following commercial products (requiring Trademark®) are mentioned in this report. Because of the frequency of usage, the Trademark was not indicated. If it becomes necessary to reproduce any segment of this document containing any of these names, this notice must be included as part of that reproduction.

Silicon Graphics	Tektronix	TECHBASE
Continuum	Fiberguide	Telzel
Chromex	Torr-Seal	Teflon
Spex		

This technical report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS) where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

Bruce J Nielsen

BRUCE J. NIELSEN
Project Manager

Michael G. Katona

MICHAEL G. KATONA, PhD
Chief Scientist, Environics Directorate

Robert G. LaPoe

ROBERT G. LAPOE, Lt. Col, USAF, BSC
Chief, Site Remediation Division

Neil J. Lamb.

NEIL J. LAMB, Colonel, USAF, BSC
Director, Environics Directorate

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Available for public release.
Distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
5735

5. MONITORING ORGANIZATION REPORT NUMBER(S)
AL/EQ-TR-1993-0009 Vol II of V

6a. NAME OF PERFORMING ORGANIZATION
Applied Research Associates, Inc.

6b. OFFICE SYMBOL (If applicable)
ARA

7a. NAME OF MONITORING ORGANIZATION
Air Force Civil Engineering Support Agency

6c. ADDRESS (City, State, and ZIP Code)
RFD #1, Box 120-A, Waterman Road
South Royalton, VT 05068

7b. ADDRESS (City, State, and ZIP Code)
HQ AFCESA/RAVW
Tyndall Air Force Base, FL 32403-6001

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
Armstrong Laboratory

8b. OFFICE SYMBOL (If applicable)
EQW

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
F08635-88-C-0067

8c. ADDRESS (City, State, and ZIP Code)
139 Barnes Drive, Suite 2
Tyndall AFB FL 32403-5323

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Air Force Site Characterization and Analysis Penetrometer System (AFSCAPS); Laser Induced Fluorescence Cone Penetrometer, Volume II - Tinker AFB Site Characterization (Vol. II of V)

12. PERSONAL AUTHOR(S)
James D. Shinn, Wesley L. Bratton

13a. TYPE OF REPORT
Final

13b. TIME COVERED
FROM Mar. '92 TO Nov. '92

14. DATE OF REPORT (Year, Month, Day)
December 1994

15. PAGE COUNT

16. SUPPLEMENTARY NOTATION
Approved for Public Release. Distribution unlimited.
AL/EQW Project Manager: Bruce Nielsen; DSN 523-6227; commercial (904) 283-6227

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
fluorescence, characterization, development, demonstration, cone penetrometer, soil, groundwater, BTEX, fuels

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A prototype Laser-Induced Fluorescence-Electronic Cone Penetrometer Test (LIF-CPT) system was demonstrated at Tinker Air Force Base (Tinker AFB), Oklahoma as an innovative technology for delineating soil contamination resulting from fuel spills. Applied Research Associates, Inc. (ARA) and North Dakota State University conducted the development program for the Air Force using LIF-CPT components developed within the Triservice Site Characterization and Analysis Penetrometer System (SCAPS) effort. Major components of the system consisted of ARA's cone penetrometer system coupled with North Dakota State University's tunable laser fluorimeter. To enable rapid, efficient and minimally invasive site characterization, the LIF-CPT probe data output was linked to ARA's real-time analysis system with three-dimensional modeling and scientific visualization capabilities. Field testing at Tinker AFB was conducted to evaluate the LIF-CPT probe. During the testing program, 112 soundings at 8 contaminated sites were conducted. At select locations, soil and water samples were obtained with CPT or drilling technologies, and tested using analytical procedures to confirm the presence of fuel contamination. These results allowed the detection limits of the LIF-CPT probe to be evaluated for jet fuels. The Tinker AFB demonstration indicates that the LIF-CPT system can detect TPH concentrations to at least 100 mg/kg. the lower bound detection limit is believed to be lower than 100 mg/kg, but scatter in the analytical and LIF data precluded accurate determination of this bound. Research planned for the summer of 1993 will address determining the LIF-CPT lower bound detection limit.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
Bruce Nielsen

22b. TELEPHONE (Include Area Code)
(904) 283-6011

22c. OFFICE SYMBOL
RAVW

DD Form 1473, JUN 86

Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

(The reverse of this page is blank.)

PREFACE

This report was prepared by Applied Research Associates, Inc. (ARA), Waterman Road, South Royalton, VT 05068, under contract FO8635-88-C-0067, SETA SSG Subtask 8.00, for the Air Force Civil Engineering Support Agency, Engineering and Services Laboratory, Tyndall Air Force Base, Florida 32403-6001. North Dakota State University was a subcontractor to ARA and fabricated and assisted in demonstrating the laser spectrometry technology.

This work was sponsored by the Oklahoma City Air Logistics Command, Directorate of Environmental Management (OC-ALC/EM) and the U.S. Air Force Civil Engineering Support Agency (AFCESA). Ms. Beverly Allen of OC-ALC/EM and Mr. Bruce Nielsen of AFCESA/RAVW were the Government technical program managers.

EXECUTIVE SUMMARY

A. OBJECTIVE

The Air Force Site Characterization and Analysis Penetrometer System (AFSCAPS) project was initiated to further develop the combined technology of the U.S. Army Corps of Engineers Waterways Experiment Station's (WES) SCAPS program and the Air Force Laser Spectroscopy Program. The purpose of the program was to enable the Air Force to address characterization, remediation and post-remedial monitoring of fuel-contaminated sites in a more efficient and effective manner. The primary objectives of this program were to develop, demonstrate, and evaluate the Laser-Induced Fluorescence-Cone Penetrometer Technique (LIF-CPT) system for the characterization of petroleum fuel-contaminated sites.

B. BACKGROUND

The Department of Defense is conducting nationwide remediation efforts to clean up contaminated military and weapons facilities. It has been estimated that remediation of these DoD facilities will require expenditure of $24 billion dollars by the DoD over the next 30 years. Identifying, characterizing and developing remediation plans for these contaminated sites is a high priority for the DoD.

Potential cost savings realized through cone penetrometer-based environmental site investigations have fostered federal research and development efforts by the U.S. Army, Navy and Air Force. Together they have supported the Tri-service Site Characterization and Analysis Penetrometer System (SCAPS) program. To better characterize hazardous waste sites, improved investigative tools and methods are being developed for use with cone penetrometers. One such tool is the laser fluorimeter. Initially developed at WES, specifically for use in detecting diesel fuel marine (DFM) for the U.S. Navy, the Air Force has sponsored additional research to modify the laser fluorimeter/cone penetrometer system for use in detecting jet fuel, heating oil and gasoline-contaminated soils.

C. SCOPE

To accomplish the objectives of this project the following tasks were completed:

- evaluation of the current LIF state-of-art,
- development of specifications for the new LIF system,
- fabrication and laboratory testing/evaluation of the LIF-CPT system,
- field demonstrations and evaluations at Tinker and Carswell AFBs of the AF LIF-CPT system.

This technical report is organized in five separate volumes:

- Volume I discusses the development of the LIF-CPT system including a review of the current state-of-art of the WES SCAPS program and NDSU's research work.
- Volume II is a review of the sites investigated at Tinker AFB.
- Volume III presents results from Carswell AFB.

- Volume IV consists of comprehensive appendix of all LIF-CPT logs, boring logs, WTM plots, and demonstration, test and evaluation (DT&E) plans for both Tinker and Carswell AFB's.
- Finally, Volume V contains the laboratory analytical data for samples obtained at Tinker AFB.

D. METHODOLOGY

The WES system employed a nitrogen laser system that is limited to the emission of a single excitation wavelength of 337 nanometers (nm). This is useful for the detection of large multi-ring fuels such as DFM but it has been shown that light fuels such as jet fuels and gasoline have only weak spectral signatures when excited with a 337 nm light pulse. Excitations at shorter wavelengths, such as 280 to 290 nm for jet fuels and 260 nm for gasoline, provide much stronger and distinctive fluorescence spectra. One of the primary goals of this project was to develop and test a tunable laser that allows the investigator to select the most appropriate wavelength depending on the contaminant of interest and site conditions.

Under this program, North Dakota state University (NDSU) developed and tested a laser fluorimeter to analyze aromatic hydrocarbons in situ. The NDSU system features a full-wavelength tunable dye system with a pulsed laser (Nd:YAG), fiber optic probe and detection system. Applied Research Associates, Inc. (ARA) incorporated the laser system with a cone penetrometer truck producing a robust site assessment tool capable of quickly locating and quantifying fugitive petroleum, oil and lubricant (POL) contamination.

E. TEST DESCRIPTION

The test program consisted of two phases, (1) evaluation of the LIF-CPT probe under laboratory conditions, and (2) evaluation of the LIF-CPT probe under field conditions.

The laboratory testing consisted of three major efforts (1) selecting and characterizing representative soils from Tinker AFB, (2) evaluation of the effect of bending the fiber-optic cable on the LIF response, and (3) determining the sensitivity of the LIF system to expected fuel contaminants.

During the field demonstration and evaluation program several objectives were addressed. Primarily, this phase demonstrated that a CPT deployed LIF system could be used to locate fuel-contaminated soils to at least the regulatory limits of 100 ppm. Other criteria such as system reliability, stability and repeatability, correlation of LIF-CPT intensity to contaminate concentration and evaluation of the sources of data scatter in the chemical and LIF-CPT data were evaluated. In addition, the cost effectiveness of the LIF-CPT was evaluated as well as its ability to provide highly detailed real-time data for on-site graphical representation.

F. RESULTS

The following summarizes the results from the laboratory and field evaluations:

- Attenuation due to bending in the fiber optic cable was not significant except at the probe end where the fibers are bent 90 degrees in a 1.25 inch radius. High

mechanical stresses caused the glass fibers to separate from the nylon jacket and move relative to the focal plane resulting in unacceptable baseline levels.

- The fluorescence spectra of JP-4 and JP-5 were indistinguishable using the LIF-CPT system. The WTMs of jet fuel and heating oil were noticeably different.
- Fluorescence of PAHs dominate the emission spectra of the subject fuels for excitation in the ultraviolet region shorter than 300 nm. The optimal excitation wavelength for continuous LIF-CPT soundings is 280-290 nm or shorter.
- The variation in the fluorescence spectral distribution is dependent on the matrix (i.e., neat, dissolved, on soil).
- Humic acids' contribution to LIF in soils play an important role in the long wavelength fluorescence spectral distribution.

G. CONCLUSIONS

Evaluation of the AFSCAPS at Tinker AFB demonstrated that the combination of an LIF-CPT, onsite analytical laboratory, and onsite three-dimensional visualization software can provide more detailed and timely mapping of fuel contamination than can be accomplished by conventional drilling and sampling programs. The LIF-CPT can provide a continuous profile of the contaminant location and relative concentration with detection levels to at least the regulatory limits for TPH.

H. RECOMMENDATIONS

A two-pronged approach is recommended for future development of the LIF-CPT. One aspect should be the continuation of the field studies to provide a broader database for further evaluation of the LIF-CPT probe in a wider range of geologic settings. The other aspect should include improvements in instrumentation, and laboratory and field methods in order to establish the bias, reproducibility, and error of the LIF-CPT system for regulatory acceptance.

I. APPLICATION

The LIF-CPT system could be implemented by the Air Force as the primary technology to conduct environmental site assessments where petroleum, oils and lubricants are involved.

J. BENEFITS

This technology could significantly reduce the time / cost of conducting site assessments and provide superior data to use as a basis for choosing an appropriate remedial strategy.

K. TRANSFERABILITY OF TECHNOLOGY

Virtually all industrial contractors involved with subsurface environmental site assessments where petroleum oils and lubricants are concerned could profit from the use of LIF-CPT technology. The industry in general is constantly seeking ways to conduct business faster, cheaper, and better; CPT-LIF fulfills these criteria.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONCLUDED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

Figure	Title	Page

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

SECTION I
INTRODUCTION

A. OBJECTIVE

Applied Research Associates, Inc. (ARA) and the North Dakota State University (NDSU), under contract to the Armstrong Laboratory Environics Directorate (AL/EQ) are developing a Laser Induced Fluorescence-Cone Penetration Technique (LIF-CPT). The objective of this program is to develop a tool to speed the site characterization process for fuel-contaminated sites. Currently, the site characterization process consists of performing borings and installing monitoring wells to obtain samples for chemical analysis. This step typically takes 2 to 3 weeks to complete. The samples are then analyzed by local analytical laboratories for various chemical compounds. The turnaround in the analytical laboratories is again approximately another two to three weeks. Once the results are obtained another three to four weeks is needed to analyze the results and prepare maps of the contaminated soil zones. Typically the results are too sparse, and additional samples are needed to more accurately locate the plume extent and volume of soil requiring remediation. To obtain the needed information, the drillers have to remobilize to the site and the whole process is repeated at additional expense and time of 7 to 10 weeks.

Use of the LIF-CPT with onsite analytical services and three-dimensional graphical analyses greatly reduces the time required to characterize a site and conserves resources. LIF-CPT profiling can test approximately 200 feet of penetration per day. These 200 feet can be either two 100-foot penetrations or twenty 10-foot penetrations, depending on the nature of the site. The data obtained provide detailed soil stratigraphy and soil contamination data, identifying soil seams and contaminant layers as thin as 4 inches. The soil contaminant information can typically be confirmed the next day with onsite analytical testing of samples obtained by either the CPT or traditional drilling. All results obtained are entered into three-dimensional computer models and graphically mapped to locate areas where additional information is needed prior to demobilization. Typically, the work that was performed in 7 to 10 weeks can now be completed in 1 to 2 weeks, representing a significant reduction in time and expenses.

The objective of this contract was to develop the LIF-CPT sensor and integrate it with ARA's current integrated site characterization program. Once the required equipment was ready, the entire

site characterization philosophy was to be demonstrated at Tinker AFB. After the demonstration, the new LIF-CPT sensor and the integrated site characterization concept were to be evaluated.

B. BACKGROUND

1. Tinker Air Force Base

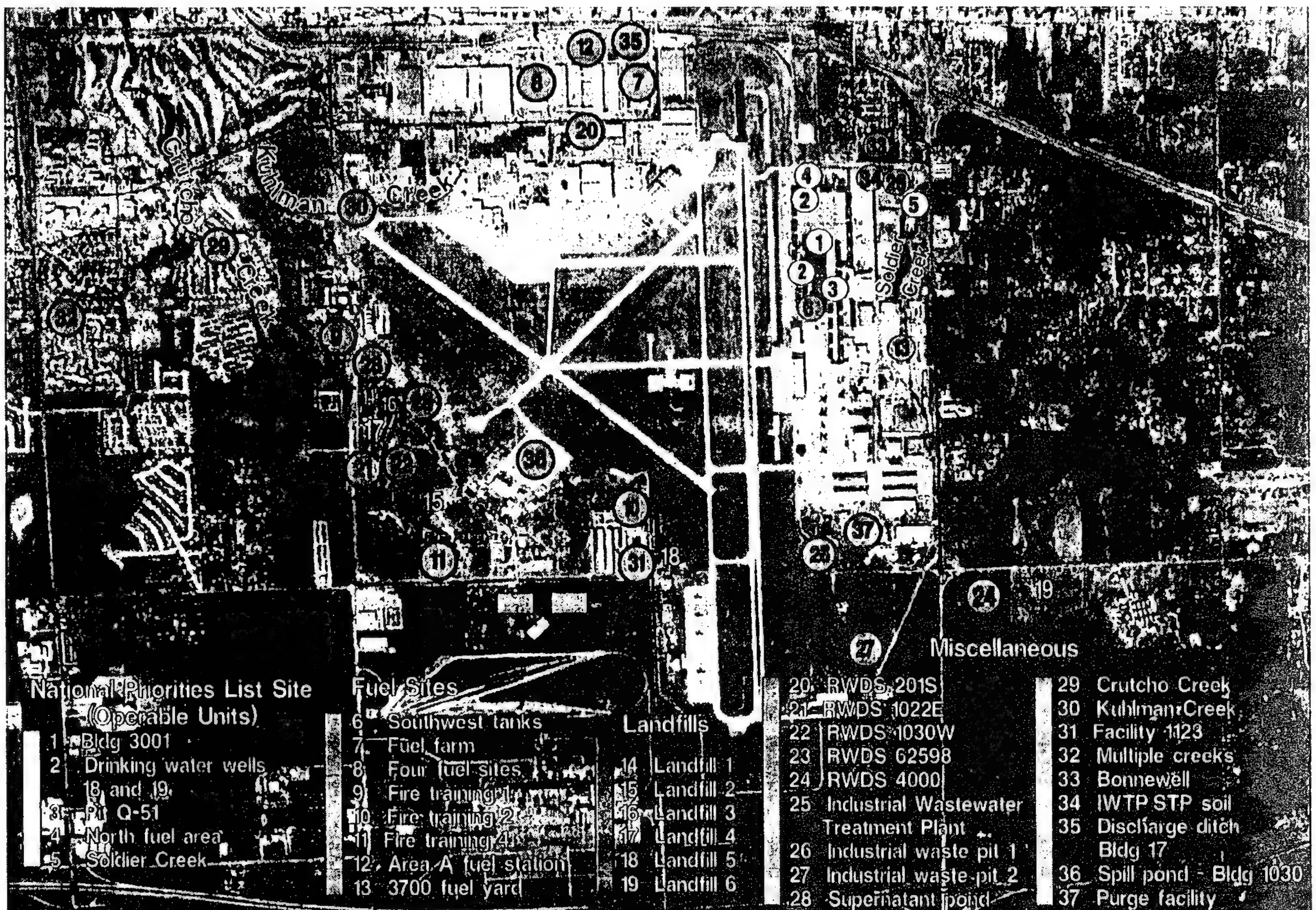
Tinker AFB is located in Midwest City, Oklahoma. The base was originally opened in the late 1940s to manufacture and service airplanes. The base is part of Air Logistic Command and routinely repairs and tests various aircraft. In achieving its mission, Tinker AFB must unload and load jet fuels into aircraft prior to repair and testing. This process involves the transportation and storage of several types of jet fuels such as JP-4, JP-5, and JP-8. In addition to these fuels, additional solvents, many containing trichloroethylene (TCE) and perchloroethylene (PCE), are used to clean parts prior to working on them.

All the fuels and many of the solvents previously or currently used are classified by the Environmental Protection Agency (EPA) as hazardous materials. These materials are transported and stored on a daily basis as part of the operations of the base, creating a potential environmental threat from leaks and spills. Tinker AFB has identified 37 sites where contamination is either known or suspected to be present, as shown in Figure 1. To locate, manage and remediate these areas, Tinker AFB has established the Directorate of Environmental Management (EM). The EM group has identified several areas of known or suspected spills located on the base. To assist the EM group with performing site characterization, this project has been developed to (1) develop and evaluate the LIF-CPT as a site characterization tool, (2) to integrate the LIF-CPT tool into the integrated site characterization concept, and (3) to provide the EM group with site geology, groundwater and soil contamination information for the seven areas of interest.

2. Overview of the Seven Areas to be Investigated

Demonstration, Testing and Evaluation (DT&E) of the prototype optical cone penetrometer system and AFSCAPS technology was performed at Tinker AFB during September, 1992. ARA prepared comprehensive work plans, sampling and analysis plans, and health and safety plans for the DT&E program. These plans are listed in Volume IV of this report.

TINKER AFB, OKLA.



1	BLDG. 3001	8	Four Fuel Sites	16	Landfill #3	24	RWDS 4000	32	Multiple Creeks
2	Drinking Water Wells	9	Fire Training #1	17	Landfill #4	25	IWTP	33	Bonnewell
	18 and 19	10	Fire Training #2	18	Landfill #5	26	Industrial Waste Pit #1	34	IWTP STP Soil
3	Pit Q-51	11	Fire Training #4	19	Landfill #6	27	Industrial Waste Pit #2	35	Discharge Ditch-BLDG 17
4	North Fuel Area	12	Area A Fuel Station	20	RWDS 201S	28	Supernatant Pond	36	Spill Pond-BLDG 1030
5	Soldier Creek	13	3700 Fuel Yard	21	RWDS 1022E	29	Crutcho CreeK	37	Purge Facility
6	Southwest Tanks	14	Landfill #1	22	RWDS 1030W	30	Kuhlman Creek		
7	Fuel Farm	15	Landfill #2	23	RWDS 62598	31	Facility 1123		

Figure 1. Photograph of Tinker AFB Showing Layout of the Base and Major Hazardous Waste Sites

The major hazardous waste sites listed by Tinker AFB's Directorate of Environmental Management are shown in Figure 1. Seven of the eight areas investigated in the DT&E (North Tank Area [NTA], Fuel Purge Area [FPA], Industrial Wastewater Treatment Plant [IWTP], East Soldier Creek and Outfall Area [OSC], Offbase - Bonnewell Area [OFB], Landfill 4 [LF4], and Landfill 2 [LF2]) are shown in Figure 2. The eighth demonstration area was the Background Area (BGA), which is located northeast of Gate 21, and represents a noncontaminated area for preliminary testing. Most of the areas studied are included within the Air Force Installation Restoration Program (IRP), with one area, the North Tank Area, being an operable unit of the Building 3001 NPL site.

A variety of contaminants are suspected or are known to have been released at the subject sites: Jet Fuel (JP-4 and JP-5), fuel oil No. 2, chlorinated solvents (e.g., TCE), and metals. Th ese contaminants have been released as surface spills, leakage from Underground Storage Tanks (USTs) or piping, and leachate from wastewater and solid waste management facilities. A summary of suspected contaminants and chemical test parameters is provided in Table 1.

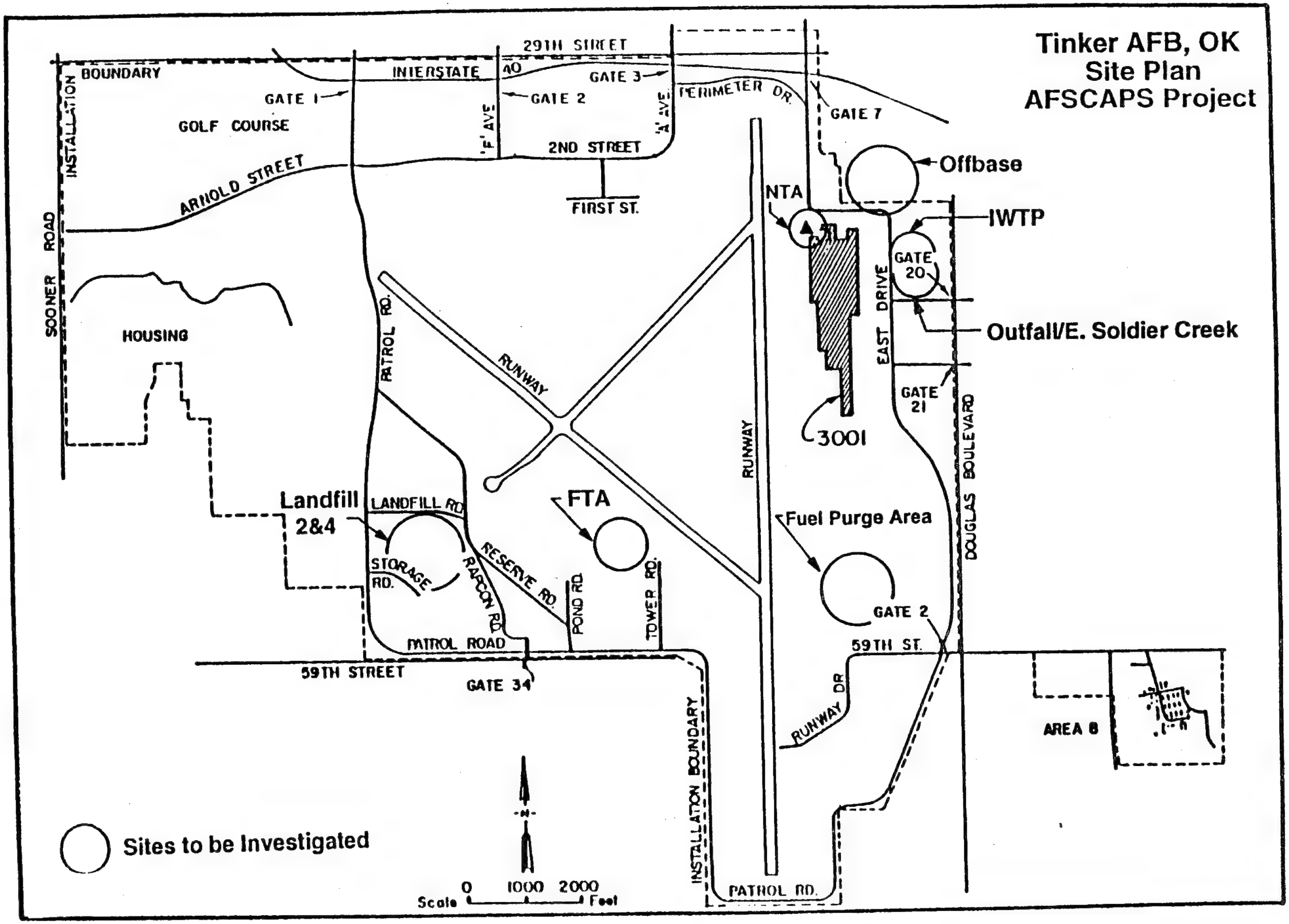


Figure 2. Layout of Tinker AFB Showing Seven Areas of Study for AFSCAPS Project.

TABLE 1. SUMMARY OF TINKER AFB SUBSURFACE CONTAMINANTS BY TEST AREA

Test Area	Contaminants Known or Suspected	Parameters of Concern
North Tank	Fuel Oil, Diesel, TCE	BTEX, TPH, VOCs
Fuel Purge	JP-4 and JP-5 Jet Fuel	BTEX, TPH, VOCs
Fire Training No. 3	Contaminated JP-4 Jet Fuel	BTEX, TPH, VOCs
IWTP	Solvents, Metals	Metals, VOCs, Semi-Vols
Bldg. 3001 Outfall	Solvents, Metals	Metals, VOCs, Semi-Vols
Offbase (Bonnewell)	Solvents	Metals, VOCs, Semi-Vols
Landfill 2	Solvents, Metals	Metals, VOCs, Semi-Vols
Landfill 4	Solvents, Metals	Metals, VOCs, Semi-Vols

Note: BTEX = Benzene, Toluene, Ethyl Benzene, and Xylene
VOCs = Volatile Organic Compounds
TPH = Total Petroleum Hydrocarbon
Semi-Vols = Semi-volatile Organic Compounds

Background information on contamination at each site ranged from nonexistent to detailed. The North Tank Area, an operable unit of the Building 3001 National Priority List (NPL) Site, had subsurface information collected during interim remedial investigations, and product recovery and tank abandonment measures performed at the site. Four sites investigated in the DT&E are listed as IRP sites: Building 3001 Outfall-East Soldier Creek, North Tank Area, Landfill No. 2 and Landfill No. 4. As suggested by their IRP listing, Tinker AFB has data substantiating these sites as being contaminated to some extent. The Industrial Wastewater Treatment Plant, Fuel Purge Facility, Fire Training No. 3 and the Offbase (Bonnewell) sites are areas that are possible candidate IRP sites. Little subsurface data exists for these sites.

3. Shallow Soil and Groundwater Conditions

Shallow subsurface materials investigated at Tinker AFB are residual soils, i.e., derived from weathering of bedrock. The local bedrock is a thick Permian-aged, sandstone and shale red-bed sequence, composed of the Hennessey Group (shale with interbedded siltstones and sandstone) and the older Garber-Wellington Formation (sandstone with interbedded siltstone and shale). The predominant soil type at Tinker is sandy clay, a byproduct of the Hennessey shales. Surface

geologic studies in the Tinker AFB area suggest (1) the contact between the Garber-Wellington Sandstone and overlying Hennessey Shale is gradational, (2) the Garber Wellington Formation outcrops to the east of Tinker AFB, and 3) 10 to 50 feet of weathered Hennessey shales and siltstones overlie the base (1).

Two distinct phreatic groundwater flow systems are identified at Tinker AFB: a deep regional aquifer (Garber-Wellington Aquifer) and a variable shallow perched system. Although the perched water table is most directly affected by anthropogenic activity, both the deep semi-confined aquifers and shallow perched groundwater system have instances of contamination.

The Garber-Wellington Aquifer is essentially confined by the Hennessey Formation and/or residual soils across the site. The Garber-Wellington aquifer, having potential well yields of 400 gallons per minute, is a public and private drinking water supply for the region. The static water level of the producing zone is typically located about 100 feet below the site. Tinker AFB straddles a subsidiary groundwater divide within the aquifer. Multi-level well data indicate that there is a strong downward component to groundwater movement at the site, consistent with the regional recharge setting.

Investigations within the DT&E address the shallow perched system and upper water bearing zones. These shallow flow zones are generally related to water-bearing sand or sandstone lenses located between sandy clay or shale units. Thin discontinuous layers of sandstone or siltstone are generally found at shallow depths (5 to 20 feet) within the Hennessey Shale at Tinker AFB. In most cases, perched water layer lies within or below these sandstone lenses. Additionally, the presence of poor surface drainage conditions or weathering features such as mineralized layers and fractures may give rise to shallow water-bearing zones at Tinker AFB.

The shallow sandstone layer is relatively unweathered and consolidated compared to the weathered shale, or has been strengthened by mineralization. Consequently, the sandstone behaves as competent rock and, depending on the thickness, is commonly resistant to cone penetrometer testing and standard auger drilling.

Table 2 lists the approximate perched water level and depth to competent rock at each of the test areas. Values listed in parentheses were provided in the DT&E plan. The table indicates that the DT&E estimates for depth to groundwater were somewhat deeper than what was measured. In addition the depth to CPT refusal, i.e. deep to component rock, was also deeper than estimated in the DT&E.

TABLE 2. AVERAGE SITE SUBSURFACE CONDITIONS, TINKER AFB

Test Area	Average Depth to Refusal	Average Depth to GW[a]
Background	10	--
North Tank	14 (10)	12 (15)
Fuel Purge	17 (12)	13 (15)
Fire Training	10 (12)	12 (15)
IWTP	8 (6)	14 (13)
Bldg. 3001 Outfall	4 (5)	7 (2)
Offbase	7 (7)	6 (15)
Landfills 2 & 4	(--)	10 (10)
Total or Range	4-17 (5-12)	7-14 (2-15)

Note: Values determined from DT&E results, values in parentheses were estimated within the DT&E plan.
a) A maximum seasonal variation of 8 feet is estimated from well data.

C. SCOPE

To demonstrate the AFSCAPS, a 30-day demonstration was planned at Tinker AFB. The demonstration program provided Tinker AFB with needed site characterization information while providing valuable field testing information concerning the LIF-CPT. During the 30-day demonstration, seven areas and one background area were investigated using the above site characterization philosophy. Tip stress, sleeve friction and pore pressure were measured in real-time to classify soil type as a function of depth. LIF intensity with depth was plotted in real-time as well. The LIF-CPT results were used to determine subsurface sampling locations. ARA's mobile gas chromatography laboratory and an off-site certified laboratory performed analytical tests on soil and water samples for comparison to the in-situ LIF results.

An extensive soil and water sampling and testing program was carried out in addition to the LIF-CPT technology demonstration. Depending on the particular site, the sampling and analysis portion of the DT&E was used to characterize the nature and extent of total petroleum hydrocarbons, volatile organic and semivolatile organic compounds, and metals. Each site investigation generally involved site reconnaissance mapping and survey, LIF-CPT profiling, soil sampling from CPT and drilling, water sampling from CPT and open drill holes, onsite gas chromatography, and off-site analytical testing. Waste management, decontamination procedures, and grouting were performed as part of the program as well.

As part of the AFSCAPS demonstration, LIF-CPT data was transferred to a Silicon Graphics® workstation for onsite analysis. Relational database, statistical modeling and scientific visualization software were implemented to produce three-dimensional images of LIF intensity. Visualization of LIF results at three fuel-contaminated sites (North Tank Area, Fuel Purge Area, and Fire Training Area 3) illustrated the lateral and vertical extent of contamination.

D. REPORT ORGANIZATION

Section II of this report contains a description of the LIF-CPT testing method and documents the field techniques, calibration methods, data acquisition system, and grouting methods used during the DT&E. Background information and calibration techniques for the LIF are discussed in Volume I of this report. The drilling and sampling methods used during the demonstration are documented in Section II of this Volume. Also presented in Section II are the analytical testing methods used to determine the various chemical contaminants present in the sample testing operations. Section III contains the analyses procedures used to interpret the CPT data into soil classification information. Data interpretation methods for the LIF are also included in this section. The techniques used to graphically display the resulting data in three-dimensions is discussed in Section III. Section IV contains detailed analyses of the information obtained for each of the seven sites. Summary and Conclusions are presented in Section V. Volume IV of this report contains appendices of the LIF-CPT profiles and boring logs for each area, Wavelength Time Matrices (WTM's), and the plans for the DT&E program. The analytical laboratory testing data sheets are presented in Volume V for each area sampled.

SECTION II

TESTING EQUIPMENT AND PROCEDURES

A. INTRODUCTION

This section summarizes the technical approach of the demonstration program, and actual field activities performed during the program. Amendments to the Work Plan and Sampling and Analysis Plan made during the demonstration program have been noted. The DT&E Plan, included in Volume IV of the technical report, is used as a guideline and is frequently referred to for details.

ARA's field crew, including Cone Penetrometer Testing (CPT) vehicle, Mobile Gas Chromatograph (GC) Laboratory, and support vehicles, arrived at Tinker on August 29, 1992. The DT&E program officially commenced on September 1, 1992 with operational testing of the LIF-CPT probe. CPT profiling and sampling were completed October 3, 1992. To achieve the DT&E sampling objectives, drilling was performed for 9 days during late September. Onsite GC testing along with onsite computer visualization was performed throughout the DT&E program.

B. TECHNICAL APPROACH

1. LIF-CPT Testing

The electronic cone penetrometer test (CPT) was originally developed for use in loose sands and clay soils. Over the years, cone and push system designs have evolved to the point where they can now be used in strong cemented soils and even soft rock. ARA's penetrometer consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck, with the weight of the truck providing the necessary reaction mass. The probe has a conical tip and a friction sleeve that independently measures vertical resistance beneath the tip as well as frictional resistance on the side of the probe as functions of depth. A schematic view of ARA's LIF-CPT penetrometer probe is shown in Figure 3. A pressure transducer in the cone is used to measure the pore water pressure as the probe is pushed into the ground (Piezo-CPT). The probe may also include three seismic transducers used to perform downhole seismic surveys. In addition,

an electrical resistivity module may be attached to the cone assembly to measure variances in soil resistivity, which assists in locating contamination plumes.

a. Piezo-Electric Cone Penetration Testing

The cone penetrometer tests are conducted using the ARA penetrometer truck. The penetrometer equipment is mounted inside an 18-foot van body attached to a 10-wheel truck chassis with a turbo-charged diesel engine. Ballast in the form of metal weights and a steel water tank, which can hold 5,000 pounds of water, are added to the truck to achieve an overall push capability of 45,000 pounds. This push capacity is limited in strong soils by the structural bending capacity of the 1.405-inch outer-diameter (OD) push rods, and not the weight of the truck. There is the possibility of the push rods buckling, which is the reason for the current 45,000 pound limitation. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame.

The penetrometer probe is of standard dimensions, having a 1.405-inch diameter, 60° conical tip, and a 1.405-inch diameter by 5.27-inch long friction sleeve. The shoulder between the base of the tip and the porous filter is 0.08 inch long. The penetrometer is normally advanced vertically into the soil at a constant rate of 48 inches per minute, although this rate must sometimes be reduced as hard layers are encountered and also when the LIF probe is being used. The electronic cone penetrometer test is conducted in accordance with ASTM D3441 (Reference 2).

Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross section inside the probe which is instrumented with four strain gages in a full-bridge circuit. Forces are sensed by the load cells and the data is transmitted from the probe assembly via a cable running through the push tubes. The analog data is digitized, recorded, and plotted by computer in the penetrometer truck. A set of data is normally recorded each second, for a minimum resolution of about one data point every 0.8 inch of cone advance. The depth of penetration is measured using a string potentiometer mounted on the push frame.

As shown in Figure 3, the piezo-cone probe senses the pore pressure immediately behind the tip. Currently, there is no accepted standard for the location of the sensing element. ARA

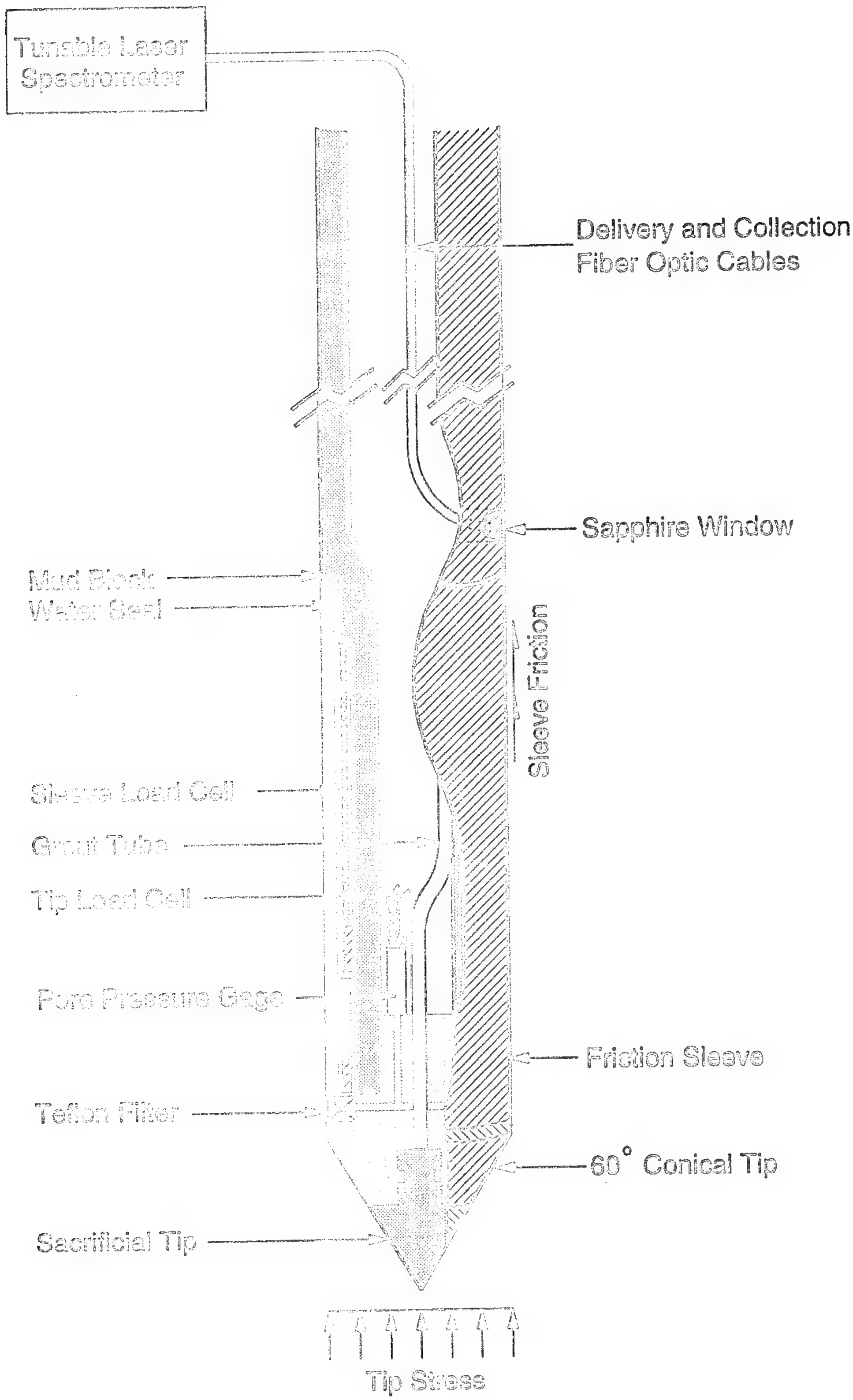


Figure 3. Schematic of ARA's LIF-CPT Probe.

chose to locate the sensing element behind the tip as the filter is protected from the direct thrust of the penetrometer and the measured pore pressure can be used to correct the tip resistance data (see Section III) as recommended by Robertson and Campanella (3). The magnitude of the penetration pore pressure is a function of the soil compressibility and, most importantly, permeability. In freely draining soil layers, the measured pore pressures will be very close to the hydrostatic pressure computed from the elevation of the water table. When low permeability soil layers are encountered, excess pore pressures generated by the penetration process can not dissipate rapidly; this results in measured pore pressures significantly higher than the hydrostatic pressures. Whenever the penetrometer is stopped to add another section of push tube, or when a pore pressure dissipation test is run, the excess pore pressure may begin to dissipate. When the penetration is resumed, the pore pressure quickly rises to the level measured before the penetrometer was stopped. This process causes some of the spikes that may appear in the penetration pore pressure data.

Electronic data acquisition equipment for the cone penetrometer consists of an IBM-compatible 486 computer with a graphics monitor and a rack of eight customized signal conditioners. Analog signals are transmitted from the probe to the signal conditioners where the CPT data is amplified and filtered at 1 Hz. Seismic signals are amplified as required and filtered at 1000 Hz. Once amplified, the analog signals are transmitted to a MetraByte Hi Res 16 bit high speed analog-to-digital converter board, where the signals are digitized; usually at the rate of one sample per second for penetration data and 5,000 samples per second for seismic data. The digital data are then read into memory, plotted on a graphics monitor, and written to the internal hard disk for future processing. Data displayed on-screen can be used to determine site layering as it is encountered. This allows important decisions to be made in real-time directly in the field. Upon completion of the test, the penetration, dissipation, and resistivity data are plotted. Plots can typically be available within 30 minutes of completing the test. Floppy disks containing the data are brought to both ARA's onsite analysis office for three-dimensional visualization and ARA's New England Division in South Royalton, Vermont, for preparation of final report plots and analysis.

b. Saturation of the Piezo-Cone

As shown in Figure 3, penetration pore pressures are measured with a pressure transducer located behind the tip in the lower end of the probe. Water pressures in the soil are sensed through

a 250 μin porous polyethylene filter that is 0.25-inch high and 0.202-inch thick. The pressure transducer is connected to the porous filter through a pressure port as shown in Figure 3. The pressure port and the filter are filled with a high viscosity silicone oil.

If the pressure transducer is to respond rapidly and correctly to changing pore pressures upon penetration, the filter and pressure port must be saturated with oil upon assembly of the probe. A vacuum pump is used to deair the silicone oil before use and also to saturate the porous filters with oil. The probe is assembled with the pressure transducer up and the cavity above the pressure transducer filled with deaired oil. A previously saturated filter is then placed on a tip and oil is poured over the threads. When the cone tip is then screwed into place, excess oil is ejected through the pressure port and filter, thereby forcing out any trapped air.

Saturation of the piezo cone is verified with field calibrations performed before the probe is inserted into the ground. The high viscosity of the silicone oil coupled with the small pore space in the filter prevents the loss of saturation as the cone is pushed through dry soils. Saturation of the cone can be verified with a calibration check at the completion of the penetration. Extensive field experience has proven the reliability of this technique with no known case where saturation of the piezo cone was lost.

c. Field Calibrations

Many factors can effectively change the calibration factors used to convert the raw instrument readouts, measured in volts, to units of force or pressure. As a quality control measure, as well as a check for instrument damage, the load cells, the pressure transducer, and the LIF sensor are routinely calibrated in the field. Calibrations are completed with the probe ready to insert into the ground so that any factor affecting any component of the instrumentation system will be included and detected during the calibration.

The tip and sleeve load cells are calibrated with the conical tip and friction sleeve in place on the probe. For each calibration, the probe is placed in the push frame and loaded onto a precision reference load cell. The reference load cell is periodically calibrated in ARA's laboratory against NIST traceable standards. To calibrate the pore pressure transducer, the saturated probe is

inserted into a pressure chamber with air pressure supplied by the compressor on the truck. The reference transducer in the pressure chamber is also periodically calibrated against an NIST traceable instrument in ARA's laboratory. Additionally, the string potentiometer, used to measure the depth of penetration, is periodically checked against a tape measure.

Each instrument is calibrated using a specially-written computer code that displays the output from the reference device and the probe instrument in graphical form. During the calibration procedure, the operator checks for linearity and repeatability in the instrument output. At the completion of each calibration, this code computes the needed calibration factors using a linear regression algorithm. In general, each probe instrument is calibrated at the beginning of each day of field testing. Furthermore, the pressure transducer is recalibrated each time the porous filter is changed and the cone is resaturated. Calibrations are also performed to verify the operation of any instrument if damage is suspected.

The LIF module is calibrated after the CPT probe has been calibrated. This is performed by placing a cuvette containing 2.5 percent JP-4 in hexane next to the sapphire window. The fluorescence response is set to 4095 on the laser computer. This causes a "count" of LIF response to represent 1/4096 (1 bit) of the area under the time decay curve of the calibration solution.

d. LIF-CPT Operations

Subsurface contamination in the shallow unsaturated zone and in the perched water table system was assessed using the prototype LIF-CPT probe as well as sampling with the cone penetrometer. As part of the field activities, all stations were flagged, surveyed and cleared for utilities prior to testing or sampling. The surveyor used control points and benchmarks established by the Tinker AFB civil engineers to establish horizontal coordinates (Oklahoma State Plane Coordinate System) and elevation (USGS-determined mean sea level). Preparing and obtaining the permits were mainly the responsibility of the Tinker AFB project coordinator. Concrete and pavement coring were performed subsequent to receiving the digging permit approvals. All holes were grouted and filled with concrete.

The actual time spent at each site is presented in Table 3. This time typically differs from the time allocated in the demonstration program plan due to decisions made in the field. For instance, the Background Area test site near Gate 21 off Douglas Boulevard was added to validate the LIF signal at a non-fuel-contaminated site prior to entering the NPL-listed North Tank Area. The field time at the North Tank Area and the Fuel Purge was essentially doubled in order to expand the demonstration of the LIF-CPT system and account for a slower-than-normal push rate. Additionally, the LIF-CPT probe identified and was used to delineated a previously unknown fuel spill site at the Fuel Purge Area. To accommodate the expanded scope at these sites, the USTs (4 Fuels) site was eliminated and field time at Landfills 2 and 4 was scaled back by 50 percent.

As shown in Table 3, a total 1,506 feet of CPT soundings were completed at 112 locations. The LIF sensor was used at 81 locations totalling 1,273 feet in approximately 16 days of field operations, a significant number for a prototype system. General CPT field operations are reviewed in the following paragraphs.

Depths of up to 21 feet were penetrated in the residual fine sand and sandy clay soils at the Fuel Purge Area. Total penetration depths of less than 7 feet occurred in areas where dense silty fine sand occurred at shallow levels, for example, near East Soldier Creek. Overall, depths achieved by the cone penetrometer slightly exceeded those expected in the demonstration program plan (see Table 2). In general, CPT depths were often 5 feet deeper than expected.

Care was taken during the pushing not to exceed the strength of the probe. The reaction mass for penetrometer vehicle is estimated to be 50,000 pounds, equivalent to a maximum tip stress of about 33,000 pounds per square inch (psi). To achieve deeper penetration, most of the initial sites (Background Area and North Tank Area) were pushed using the maximum load with cycling. This allowed penetration beyond a 1- to 2-foot thick sandstone layer found at the Background Area to increase the total depth from 6 feet to 10 feet. However, this technique resulted in breakage of the LIF-CPT probe at station NTA-04 in the North Tank Area. The maximum tip stress used thereafter was less than 10,000 psi. Occasionally, refusal in the CPT was attributed to high frictional stresses on the side of the cone as opposed to compressional stresses at the tip. While expander CPT rods may have enabled deeper penetration by reducing the net frictional stresses on the rod, they were not used during the demonstration.

TABLE 3. SUMMARY OF TINKER AFB DT&E CPT AND BORING WORK

Test Area	Field Time	Total Locations	LIF-CPT or CPT Profiles		CPT Soil Sample Locations		Drilling Locations		Water Sampling Sites
	days		No.	T. Ft.	No.	T. Ft.	No.	T. ft.	No.
Background	1	4	4	41	0	0	0	0	0
North Tank	8	11	11	154	1	55	10	172	10
Fuel Purge	12	55	55	927	9	287	6	154	6
Fire Training	2	8	8	82	0	0	2	29	1
IWTP	2.5	8	0	0	0	0	8	142	7
Bldg. 3001 Outfall	1	5	7a	20	0	0	2	29	0
Offbase	1.5	4	2	15	2	20	2	46	0
Landfill No.2	2.5	11	11	114	4	68	0	0	5b
Landfill No. 4	2.5	14	14	153	3	53	0	0	2
Totals	33	120	112	1,506	19	463	30	572	31

Note: Field time includes usage days for CPT and drilling

a) 3 of the 7 pushes were offset holes, paired with an initial push to confirm shallow refusal.

b) Water samples retrieved from existing piezometers at the site.

e. CPT Soil and Groundwater Sampling

The total cone penetrometer footage for soil sampling was 463 feet, with 49 samples retrieved at 19 locations. The high frequency of sampling (e.g., 5, 10 and 15 feet sample depths) limited maximum footage rates to 150 feet/day. As discussed in the Sampling and Analysis Plan (Appendix M of Volume IV), two types of CPT soil samplers were used. The large-volume soil samplers (Mostap®) had some limitations due to the stiff soils encountered. In some cases, a dummy probe was pushed to the desired depth and extracted. The Mostap® soil sampling probe was then pushed to retrieve the sample. The small-volume Gouda® sampler is more robust and consequently had fewer problems. Besides poor recovery encountered in landfill refuse, the CPT retrieved full-capacity soil samples.

Decontamination procedures for the sampling equipment as described in the DT&E plan were followed. Due to the shallowness of the CPT pushes, use of an extra field technician dedicated to decontamination and sample handling was found to expedite the sampling process. Duplicate sampling apparatus would also speed operations by reducing the decontamination time. Upon retrieval at the surface, all samples tubes were sealed, chilled on ice, and transported to the mobile laboratory for analysis or transfer to the off-site lab.

Use of the CPT water sampler was limited to only two samples. There were few cases where an adequately thick saturated zone was located above the competent sandstone layer. If there was, the abundance of silt and clay in the residual soil created very slow recovery times for infiltrating the hole. Therefore the majority of water samples were retrieved from the open drill holes.

f. Decontamination

The CPT push rods were cleaned with ARA's CPT steam-cleaning system (rod-cleaner) as the rods were withdrawn from the ground. A vacuum system was developed during the demonstration program, which resulted in nearly 100 percent recovery of steam-cleaning rinsate from the rod-cleaner located beneath the truck. Rinsate was generated only as the rods moved past the cleaner, thereby minimizing liquid waste generation. Care was taken not to apply the

pressurized steam to the LIF module. The vacuum system pulled the rinsate into 55-gallon drums located in the rear of the support vehicle's trailer. When full, the barrels were emptied into a wastewater storage tank dedicated for the project.

Changes to the CPT rod decontamination procedures were made after initial verification of the LIF signal as being related to contamination. To save time and reduce waste generation, rods were wiped down with disposable towels instead of steam-cleaned, where permissible. This was generally the case at petroleum site locations where no LIF "hits" were measured.

g. Grouting

To maximize the quality and quantity of LIF-CPT information, the grouting procedure was changed from using pressurized cement grouting to pouring 1/4-inch bentonite pellets in the CPT hole. Sealing shallow holes with bentonite was deemed adequate since there was no significant threat of cross-contamination in the soil column intruded. Due to the tight schedule in the probe development, the self-grouting CPT probe was not tested during the field demonstration program.

2. Hollow-Stem Auger Drilling Summary

In addition to CPT sampling, conventional borings were advanced to retrieve both soil and water samples. A modified-hollow stem auger with a bearing-head sample tube system was chosen as the drilling method. The method possessed a good track record for penetrating the upper weathered sandstone at Tinker AFB and obtained reasonably undisturbed and continuous soil samples in 5-foot core barrels. The total drilling footage was 572 feet at 30 locations; drill holes were generally located where LIF-CPT profiling had been performed. Drilling was used exclusively at the IWTP due to the known shallow refusal depths (Table 2). Samples were laid out on plastic sheets and logged. Logs of the drilling core are presented in Appendix I of Volume IV. Samples were taken and placed in appropriate containers, either 40-ml glass vials or 1-quart jars. The samples were chilled and stored in an ice chest prior to onsite testing or transferral to the off-site analytical laboratory.

Twenty-four water samples were taken from the open drill holes. The drill holes were generally left open to recharge overnight and the water levels were recorded the next day (see Table 2). Some slumping in the holes occurred which necessitated overdrilling on occasion. Since the holes were not cased or secured, water did not exclusively enter the borehole from the phreatic zone. Water sampling was accomplished using a decontaminated PVC bailer and were grab samples. After sampling, the holes were grouted using a portland cement-bentonite mix.

Augers were steam-cleaned prior to drilling. A decontamination pad was set up next to the wastewater storage tank, with the rinsate water pumped directly into the tank. Unlike the cone penetrometer, drilling extracted contaminated soils which had to be drummed and ultimately disposed at a RCRA facility. Twenty barrels of drilling waste were produced. Contents of one to three drums from each test area were composited and tested using TCLP methods and is presented in Appendix O of Volume V. The waste management and approval process for proper disposal of the drilling solid waste and rinsate water has required more than two months' time.

3. Chemical Testing

a. Onsite Gas Chromatography

As shown in Table 4, ARA's mobile gas chromatograph laboratory tested approximately 128 soil and water samples for either a suite of selected aromatic hydrocarbons or selected chlorinated hydrocarbons. The North Tank Area and Fuel Purge Area had aromatics tested (BTEX, naphthalene, and 2-methyl naphthalene), and the rest of the sites were tested for the chlorinated series (methylene chloride, trichloroethene, 1,1,1-trichloroethane, 1,2-dichloroethane, and 1,1-dichloroethene). A HP-5890 Series II Gas Chromatograph (GC) unit, duel detectors (FID and ECD), purge and trap, and 80486-based computer running HP Chemstation® software, as stated in the Sampling and Analysis Plan, were used.

An AT-624 (Alltech®) column and FID was used for the aromatic series. The AT-5 column suggested in the plan did not adequately resolve all the BTEX compounds plus the desired naphthalenes during preliminary testing prior to mobilization to Tinker AFB. The AT-624 was used to develop a method that could measure the BTEX compounds and also two naphthalenes compounds

TABLE 4. TINKER AFB CHEMICAL ANALYSIS MATRIX

Test Area	Water VOA[a]	Water TPH	Soil VOA[b]	Soil TPH	Soil Suite A[c]	Soil Suite B[d]	TCLP[e]	LIF Profiles
North Tank	2/10, 2d	10	9/12, 5d	11	11	--	--	11
Fuel Purge	6/2, 2d	6	61/14, 13d	52	13	--	2	55
Fire Training	0/1, 0d	1	0/6, 0d	6	6	--	2	8
IWTP	7/2, 2d	0	8/3, 3d	0	--	8	2	0
Bldg. 3001 Outfall	0	0	3/0, 0d	0	--	3[d2]	1	0
Offbase	0	0	11/4, 4d	3	--	9	1	0
Landfill 2	5/5, 5d	0	8/3, 3d	4	--	4	0	7
Landfill 4	2/3, 2d	0	6/4, 4d	3	--	4	1	0
Total	22/23, 11d	17	106/46, 32d	79	30	51	18	81

Notes:

[a] X/Y - X: Water volatile organic analyses (VOA) performed in the field using GC and modified EPA methods 601/602 to scan the site-specific target compounds; Y: Water VOA performed by certified laboratory using GC/MS and EPA Method 8240.

[b] X/Y - X:Soil VOA performed in the field using modified EPA method 601/602 to scan the site-specific target compounds. Y: Soil VOA analyzed by a certified laboratory using EPA method 8240. Lab and field VOA include 20 percent splits.

[c] Suite A Parameters: T. Phenols (EPA Method 420.1), and PAHs (23 samples: HPLC method for naphthalene and 2-Methyl Naphthalene using EPA method 610; 8 samples: GC/MS using EPA method 8270 with base/neutral extraction).

[d] Suite B Parameters: T. Metals (Cd, Cr, Ba, Pb, Zn, As, Hg, Ni), T. Phenols, and PAHs (GC/MS using EPA method 8270 with base/neutral extraction).

[d2] No PAHs tested.

[e] TCLP tests for metals, volatiles and semi-volatiles performed on both grab and composite soil samples.

TPH = Total Petroleum Hydrocarbons using EPA method 418.1 (infrared analysis, freon extraction).

in a single run of just over 25 minutes using temperature programming. Resolution of all compounds was good, however, ethylbenzene and m-xylene had retention times that were only separated by 0.23 minute. The instrument was calibrated at four points (5 ppb, 50 ppb, 100 ppb, and 200 ppb) and the detection limit was determined to be 20 ppb when the scatter of the calibration data was considered.

The same AT-624 column with an ECD was used for the chlorinated series. Once again, temperature programming was used to develop a method to measure all five chlorinated compounds in a 15 minute run. Resolution of all peaks was very good, as separation between each peak was greater than 1 minute. The advantage of using the ECD for these compounds is that the ECD is highly sensitive to chlorinated compounds; however, this also effects the detection limit as the scatter is increased by even trace amounts in the reagent water. Overall the detection limit was set at 50 ppb for methylene chloride and 20 ppb for the remaining compounds.

b. Off-Site Analytical Testing

The off-site analytical testing was performed by ANALAB Corp. of Kilgore, Texas. As shown in Table 4, a total of 264 samples were tested. The test method used depended on the chemicals of interest for that particular site as described in Table 4. The VOCs were tested by EPA method 8240, TPH was tested by EPA methods 418.1, Semivolatile organic compounds by EPA method 8270, and the metals were tested by EPA methods 6010 and 7470. The off-site chemical testing data sheets are presented in Volume V of this report.

The vast majority of off-site volatile organic analyses had not been processed by the end of the demonstration, with many of the analyses being completed 2 weeks after their holding time expired. Violation of the holding times did not necessarily alter the test results significantly, but it did affect the data analysis schedule. The entire suite of analytical data was finalized in early November, approximately four weeks after the completion of the DT&E field program.

SECTION III
DATA ANALYSIS METHODS

A. INTRODUCTION

This section begins by presenting the data analysis methods that were used to interpret the numerous data types that were obtained during the DT&E phase of the project. At each of the seven sites at Tinker AFB, several data types were measured. The data types varied slightly at some sites, however, most sites received soil or water sampling, conventional drilling and logging, cone penetration testing (CPT), and LIF testing. The methods used to interpret and present these data results are presented in the following sections.

B. TECHNICAL APPROACH

1. LIF-CPT Penetration Data Format

A penetration profile, from the NTA site, is shown in Figure 4. Plotted as a function of elevation are the measured tip resistance, sleeve friction, friction ratio, and pore pressure. When the surface elevation of the test location is unknown, the penetration data is plotted against depth.

Tip resistance, q_c (lb/in^2), is obtained by dividing the vertical force on the conical tip by the effective tip area (1.550 in^2). The tip resistance is then corrected for pore pressures acting behind the conical tip as discussed below. The corrected tip resistance, q_T (lb/in^2), is plotted in the penetration profile. Sleeve friction, f_s (lb/in^2), is obtained by dividing the total frictional force on the sleeve by the sleeve's surface area (23.26 in^2). The offset between the depth at the tip and the depth at the friction sleeve is corrected by shifting the sleeve friction profile downward so that it corresponds to the depth at the centroid of the tip. In addition to the tip resistance and sleeve friction, a friction ratio profile is plotted for each location. This ratio is simply the sleeve friction expressed as a percentage of the tip resistance at a given depth. In uncemented soils, the friction ratio can be correlated to soil type. The next profile shown in Figure 4 is the pore pressure that is measured as the probe is advanced. Each of these four profiles are used to determine soil stratigraphy information as discussed below.

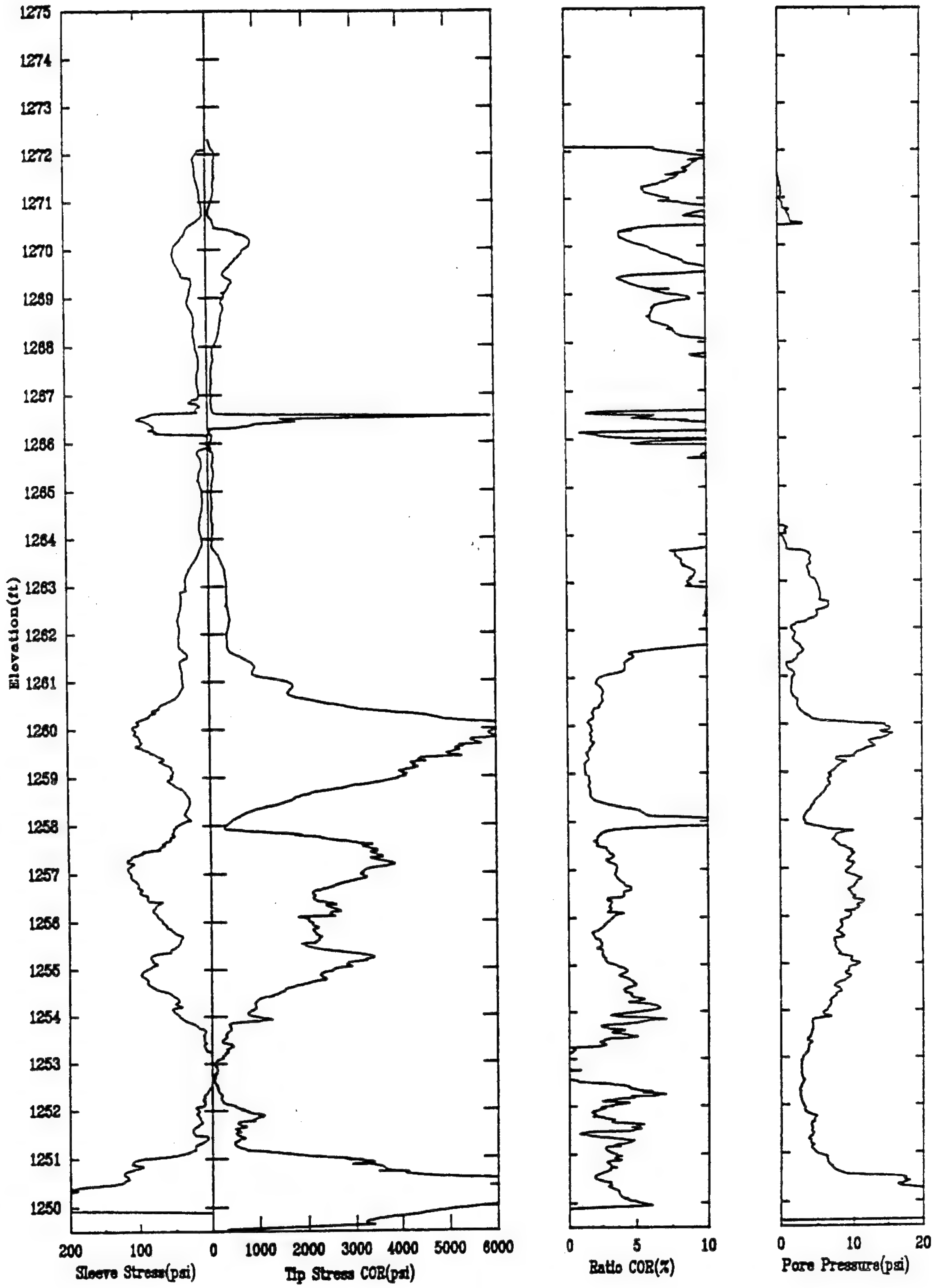


Figure 4. Typical Laser Induced Fluorescences - Cone Penetration Test Profile Along with Soil Classification.

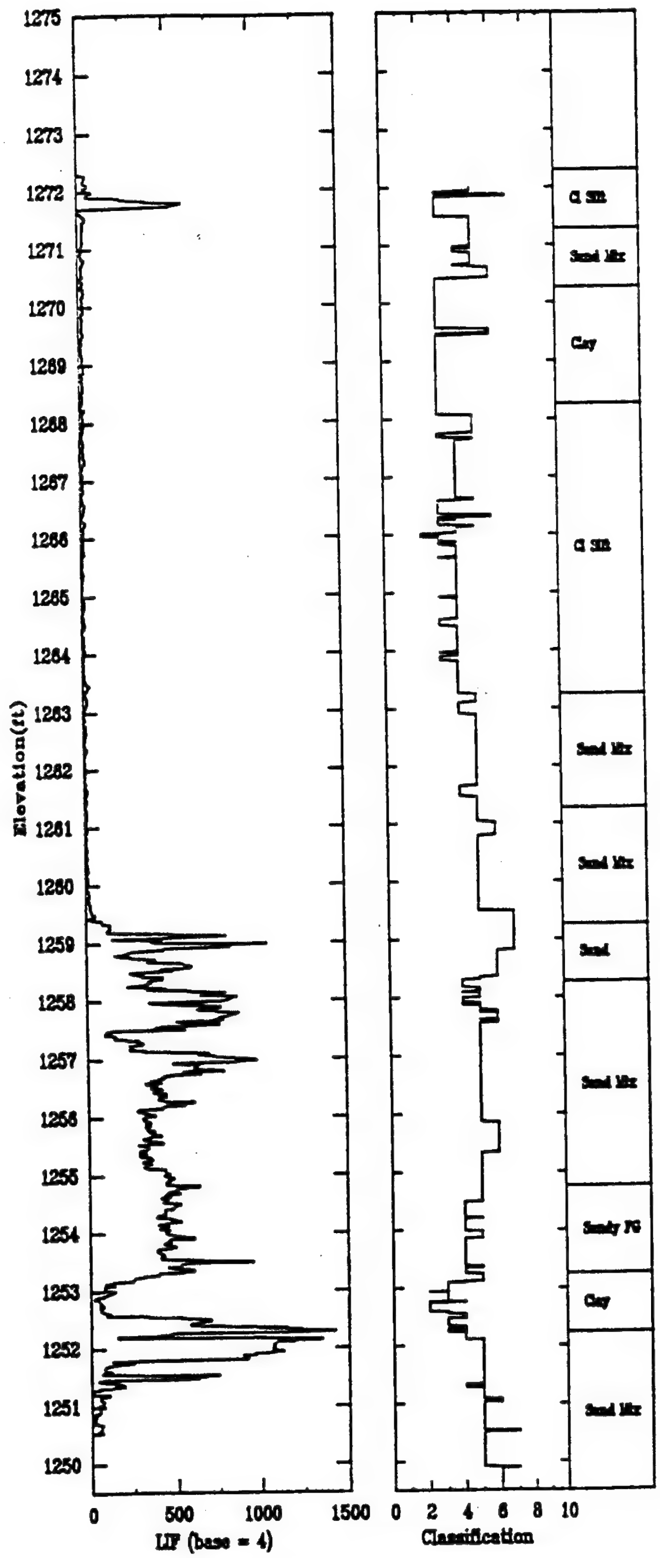


Figure 4. Typical Laser Induced Fluorescences - Cone Penetration Test Profile Along with Soil Classification (Concluded).

a. Pore Pressure Correction of Tip Stress

Cone penetrometers, by necessity, must have a joint between the tip and sleeve. Pore pressure acting behind the tip decreases the total tip resistance that would be measured if the pen etrometer was without joints. The influence of pore pressure in these joints is compensated for by using the net area concept (3). The corrected tip resistance is given by:

$$q_T = q_c + u\left(1 - \frac{A_n}{A_T}\right) \tag{1}$$

where:

q_T = corrected tip resistance

q_c = measured tip resistance

u = penetration pore pressure measured behind the tip

A_n = net area behind the tip not subjected to the pore pressure (1.257 in^2)

A_T = projected area of the tip (1.550 in^2).

Hence, for the ARA cone design, the tip resistance is corrected as:

$$q_T = q_c + u(.1890) \tag{2}$$

Laboratory calibrations have verified Equation 2 for ARA's piezo-cone design.

A joint also exists behind the top of the sleeve (see Figure 3). However, since the sleeve is designed to have the same cross sectional area on both ends, the pore pressures acting on the sleeve cancel out. Laboratory tests have verified that the sleeve is not subjected to unequal end area effects. Thus, no correction for pore pressure is needed for the sleeve friction data.

The net effect of applying the pore pressure correction is to increase the tip resistance and to decrease the friction ratio. Generally, this correction is only significant when the pore pressures are high while measured tip resistance is very low.

b. Numerical Editing of the Penetration Data

Any time that the cone penetrometer is stopped or pulled back during a test, misleading data can result. For instance, when the probe is stopped to add the next push tube section, or when a pore pressure dissipation test is run, the excess pore pressures will dissipate towards the hydrostatic pore pressure. When the penetration is resumed, the pore pressure generally rises very quickly to the pressures experienced prior to the pause in the test. In addition, the probe is sometimes pulled back and cycled up and down at intervals in deep holes to reduce soil friction on the push tubes. This results in erroneous tip stress data when the cone is advanced in the previously penetrated hole.

To eliminate this misleading data from the penetration profile, the data is numerically edited before it is plotted or used in further analysis. Each time the penetrometer stops or backs up, as apparent from the depth data, the penetration data is not plotted. Plotting of successive data is resumed only after the tip is fully reengaged in the soil by one tip length (1.22 inches) of new penetration. This algorithm also eliminates any data acquired at the ground surface before the tip has been completely inserted into the ground. The sleeve data is similarly treated and this results in the first data point not occurring at the ground surface, as can be seen in some tip and sleeve profiles. These procedures ensure that all of the penetration data that is plotted and used for analysis was acquired with the probe advancing fully into undisturbed soil.

c. LIF Intensity Data

As discussed in Volume I, the LIF module was used to make fluorescence measurements of the soils as the cone was inserted into the ground. The LIF system monitored the fluoresced light coming into the probe at a wavelength of 340 nm. The time decay of this light was recorded by the laser computer and the area under the time decay curve was then integrated to determine an intensity value. These intensity values were then averaged every four seconds, and the average transferred to the CPT computer and stored. The intensity values were recorded verses depth for each of the CPT pushes where LIF was used.

To eliminate the hole-to-hole variance of the laser intensity, the median of the minimum 41 points was used to determine a baseline value. The baseline value was then subtracted from all the readings in the profile. This produces profiles that can be compared and overlaid, since many of the variances between tests have been eliminated. The baseline corrected LIF values are the values presented in the LIF profile shown in Figure 4. The baseline value is shown at the base of the plot. LIF profiles are presented in Volume IV for all locations were LIF testing occurred.

In addition to the active measurement of intensity, a detailed measurement of the florescence time decay at several different wavelengths was also made. These data are plotted in what is referred to as a Wavelength Time Matrices or WTM. A typical WTM is presented in Figure 5. This plot represents detailed florescence data at a single point in space.

The color scale used in all the WTM plots along with the waveform time decay versus depth plots is shown in Figure 6. Using this scheme all signals greater than 0.4 volts are given the color red. No algorithms currently exist for the interpretation of this data into chemical concentration or chemical type information, therefore these plots are only used to discuss differences noticed between locations. A table containing the locations and depths of the WTMs, along with data plots is presented in Appendix K of Volume IV.

d. Soil Classification From the CPT

The tip resistance, friction ratio, and pore pressure values from CPT profiles can be used to determine soil classification versus depth. The methodology used in this report to classify the soils is based on specific empirical correlations described in Timian et al (4) and is summarized in the two charts shown in Figure 7. In general, clean, coarse-grained soils have high strengths with relatively low sleeve friction, while finer-grained soils have low strengths and high side friction (cohesion). Similarly, as shown in the second chart of Figure 7, a correlation exists between soil type and the ratio of tip stress to pore pressure response. Clean, coarse-grained soils tend to have high strengths, but are permeable and develop little or no excess pore pressure during penetration. Fine-grained soils are weak and impermeable and tend to develop high excess pore pressures during penetration.

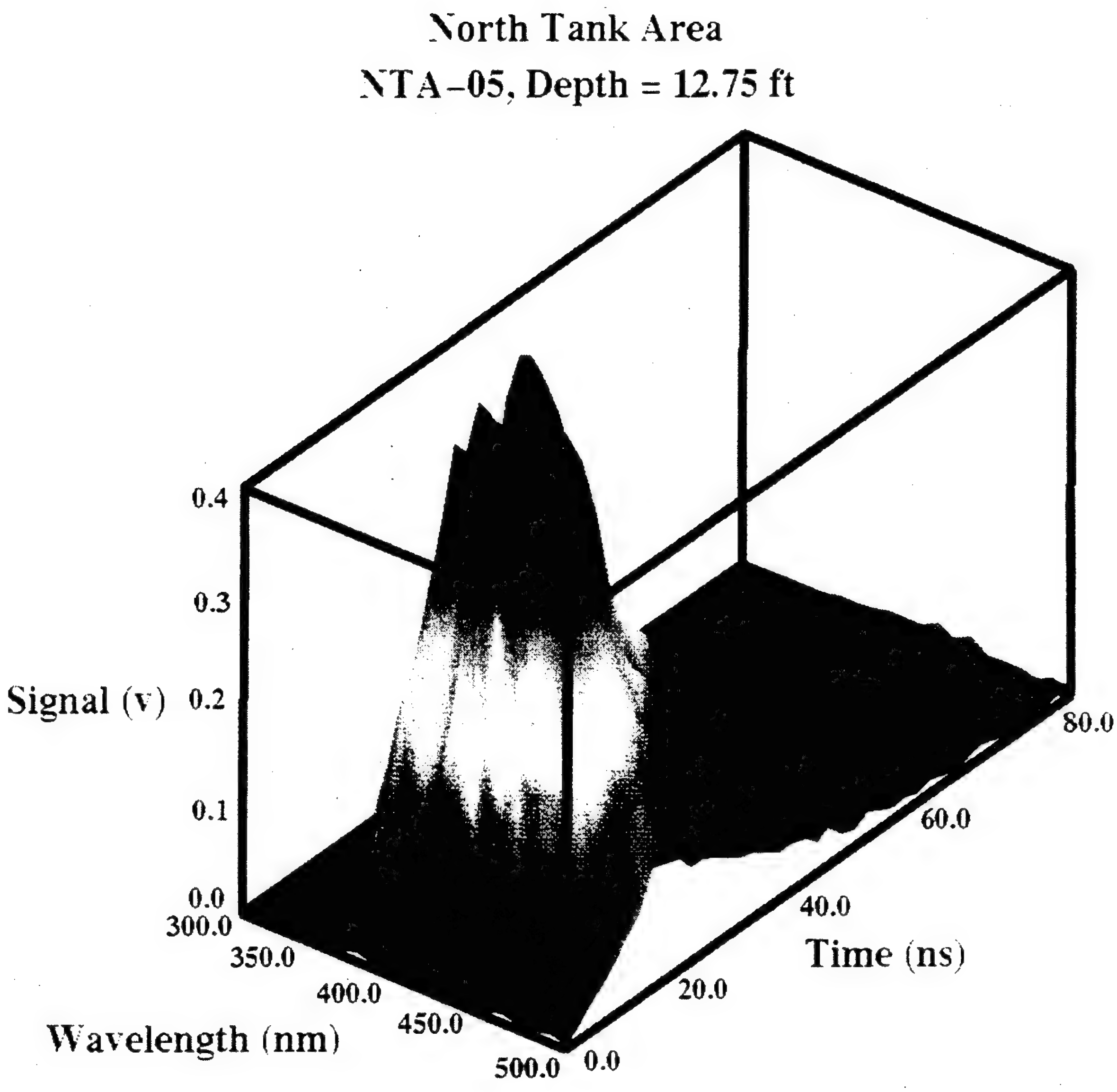


Figure 5. Example Wavelength Time Matrix Shown in Three-Dimensional Space.

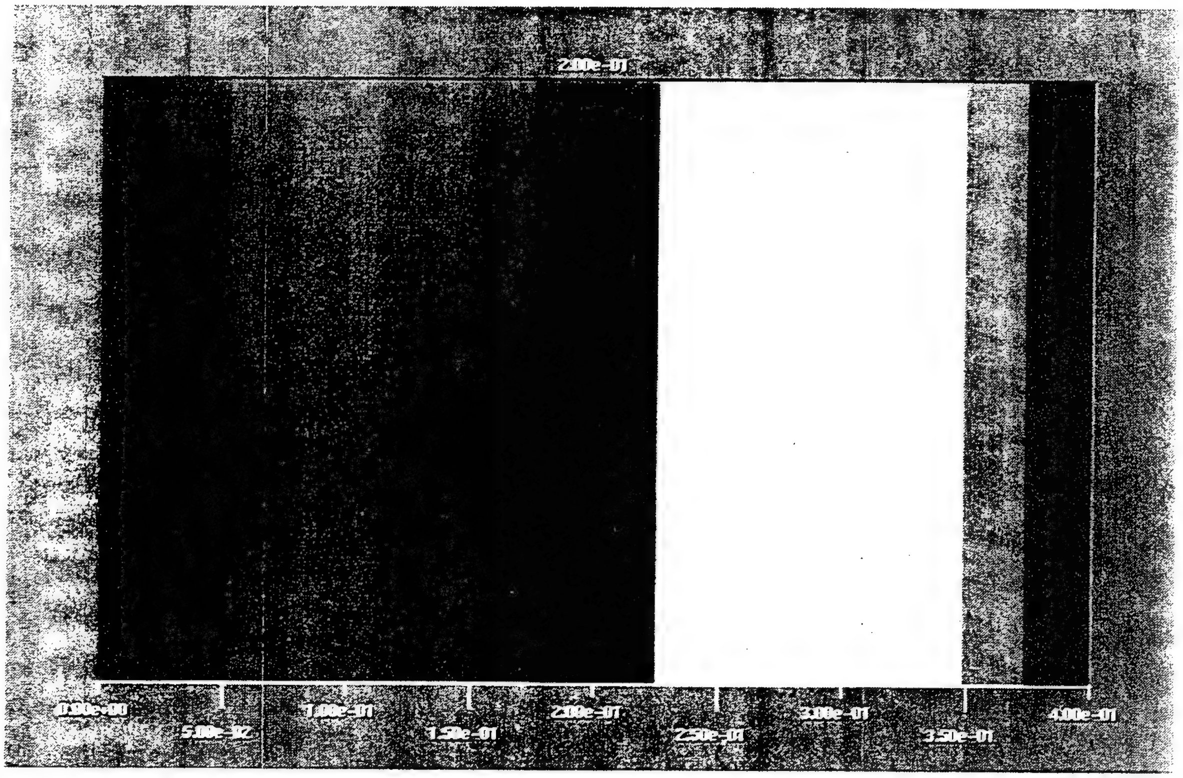
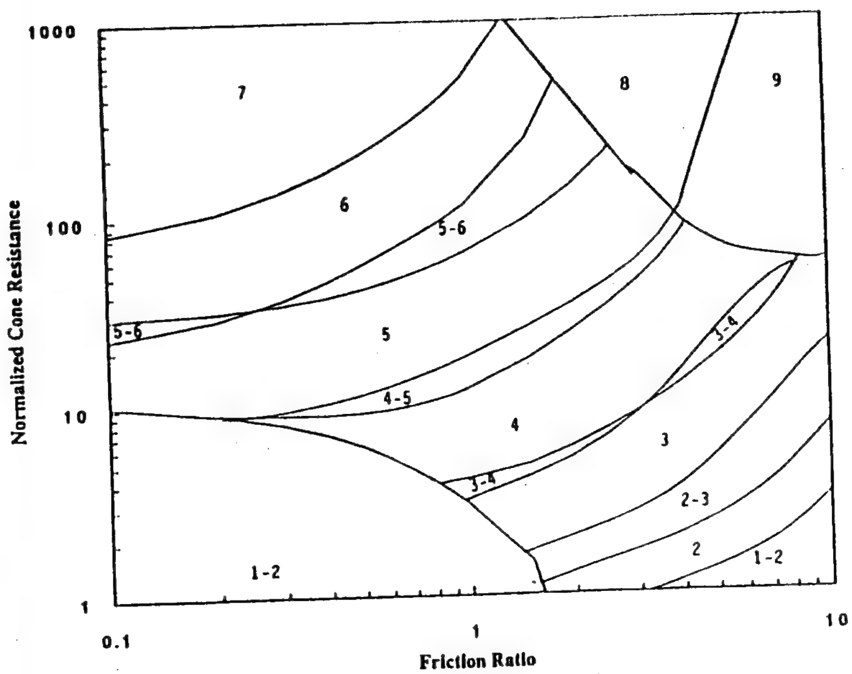
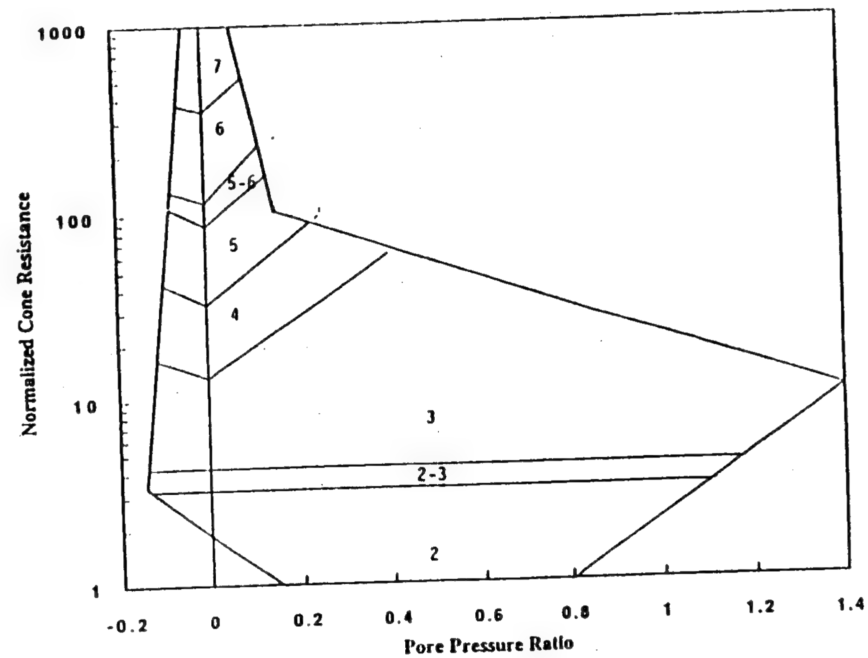


Figure 6. Color Scale Used for all WTM and Waveform Time Decay Versus Depth Plots.

Fresh Kills Friction Ratio Classification Chart



Fresh Kills Pore Pressure Classification Chart



FRICTION RATIO $\frac{f_s}{q_t - \sigma_{vo}} \times 100\%$

1. Sensitive, Fine Grained
2. Organic Soils-Peat
3. Clays - Clay to Silty Clay
4. Silty Mixtures - Clayey Silt to Sandy Silt
5. Sand Mixtures - Silty Sand to Sandy Silt

PORE PRESSURE RATIO $B_q = \frac{u - u_o}{q_t - \sigma_{vo}}$

6. Sands - Clean Sand to Silty Sand
7. Gravelly Sand to Sand
8. Very Stiff Sand to Clayey* Sand
9. Very Stiff, Fine Grained*

(*) Heavily Overconsolidated or Cemented

Figure 7. Ara's Soil Classification System Based on CPT Data.

Soil classification can be determined from the charts by comparing the normalized tip resistance to the pore pressure ratio or to the normalized friction ratio. The tip resistance is normalized according to:

$$q_n = \frac{q_T - \sigma_{vo}}{\sigma_{vo}'} \tag{3}$$

where: q_n = normalized tip stress

q_T = corrected tip resistance from Equation 2

σ_{vo} = total overburden stress

σ_{vo}' = effective overburden stress

The pore pressure ratio, B_q, is defined as:

$$B_q = \frac{u_{meas} - u_o}{q_T - \sigma_{vo}} \tag{4}$$

where: u_{meas} = measured penetration pore pressure

u_o = static pore pressure, determined from the water table elevation

and the normalized friction ratio, f_{SN} is defined as:

$$f_{SN} = \frac{f_s}{q_T - \sigma_{vo}} \; x \; 100\% \tag{5}$$

The plot of any point of the q_n versus B_q or f_{SN} value normally falls in a classification zone of Figure 6. The classification zone number corresponds to a soil type as shown in the figure. The classification zone number is then used in determination of a unified soil classification profile (described below) which is then plotted versus elevation for each penetration test as shown in Figure 4. At some depths, the CPT data will fall outside of the range of the classification chart. When this occurs, no data is plotted and a break is seen in the classification profile.

The next step in developing the soil classification profile is reconciliation of the similarities and differences between the two soil classification methods shown in Figure 6 into a single unified estimate, as shown in the classification profile indicated in Figure 4. This profile represents a point by point weighted average of the two methods, with weighting factors based on confidence levels established for each measurement used in the classifications. These confidence levels are based on measurement amplitudes, consistency, and engineering experience with CPT data.

The classification profiles are very detailed, frequently indicating significant variability in soil types over small changes in elevation. In order to provide a simplified soil stratigraphy for comparison to standard boring logs, a layering and generalized classification system was implemented (i.e., soil unit descriptions located to the right of the classification profile). A minimum layer thickness of 1.0 foot was selected. Layer thicknesses are determined based on the variability of the soil classification profile. The layer sequence is begun at the ground surface and layer thicknesses are determined based on deviation from the running mean of the soil classification number. Whenever an additional 6-inch increment deviates from the running mean by more than 0.50, a new layer is started, otherwise, this material is added to the layer above and the next 6-inch section is evaluated.

The soil type for the layer is determined by the mean value for the complete layer. The ten types are classified as:

Classification Range	Soil Type
1.00 - 2.25	Sensitive Clay
2.25 - 2.75	Soft Clay
2.75 - 3.25	Clay
3.25 - 3.75	Silty Clay
3.75 - 4.25	Clayey Silt
4.25 - 4.75	Sandy Fine Grained
4.75 - 5.75	Sand Mixture
5.75 - 6.75	Sand
6.75 - 7.50	Gravelly Sand
7.50 - 9.00	Over Consolidated (OC)

Again, a more detailed classification can be determined from the classification profile plotted just to the left of the soil type (unit) layers. The layering provides a summary of the engineering classification of soil stratigraphy.

e. Comparison Between CPT Soil Stratigraphy and Boring Logs

Overall, the computer-generated CPT soil stratigraphies compare very favorably to the soil boring logs. Figure 8 presents a typical CPT soil stratigraphy along with the soil descriptions determined by the geologist logging the soil borings. For location FPA-31, the boring log indicates three different material types. The upper-most material is a silty sand consisting of fine to medium sand. This material extends to a depth of 3.5 feet (elevation = 1281.9 feet). The computer generated soil stratigraphy agrees and identified two material types in this zone, one a sand and the other a sand mix. The second material indicated by the boring log is a silty clay extending to a depth of 11.0 feet (elevation = 1274.4 feet). This material is described as mostly silt and clay with few sand-sized particles. The CPT agrees and classifies this material to a depth of 11.7 feet as either a clayey silt, a sandy fine-grained material, or a clay. Overall, these descriptions are in agreement with the generalized classification from the boring logs. From 11.0 feet to the bottom of the boring the geologist classification is a weathered shale or siltstone. This agrees with the rapid increases in tip and sleeve stresses as reflected by a much more competent material than encountered above. Although the CPT described this as a sand mix, the tip and sleeve stresses indicate a strong, competent material such as a siltstone or fine grained sandstone. In summary the comparison between the boring and the computer generated soil stratigraphy show very good agreement and the computer generated soil stratigraphy can be used with confidence.

2. Scientific Visualization of Results in 3-D

To assist with interpretation of the numerous data variables present at each site, the data was input into a geographical database system called TECHBASE® developed by Minesoft, Inc. The system incorporates a relational database containing a wide range of tools for analysis of stored data, geostatistical modeling, and graphical capabilities to display contours, cross-sections, perspectives, and vector drawings. LIF-CPT data profiles were transferred into TECHBASE® using an acceptable data format; this required linking between a PC computer and a Silicon Graphics, Inc. Personal Iris®

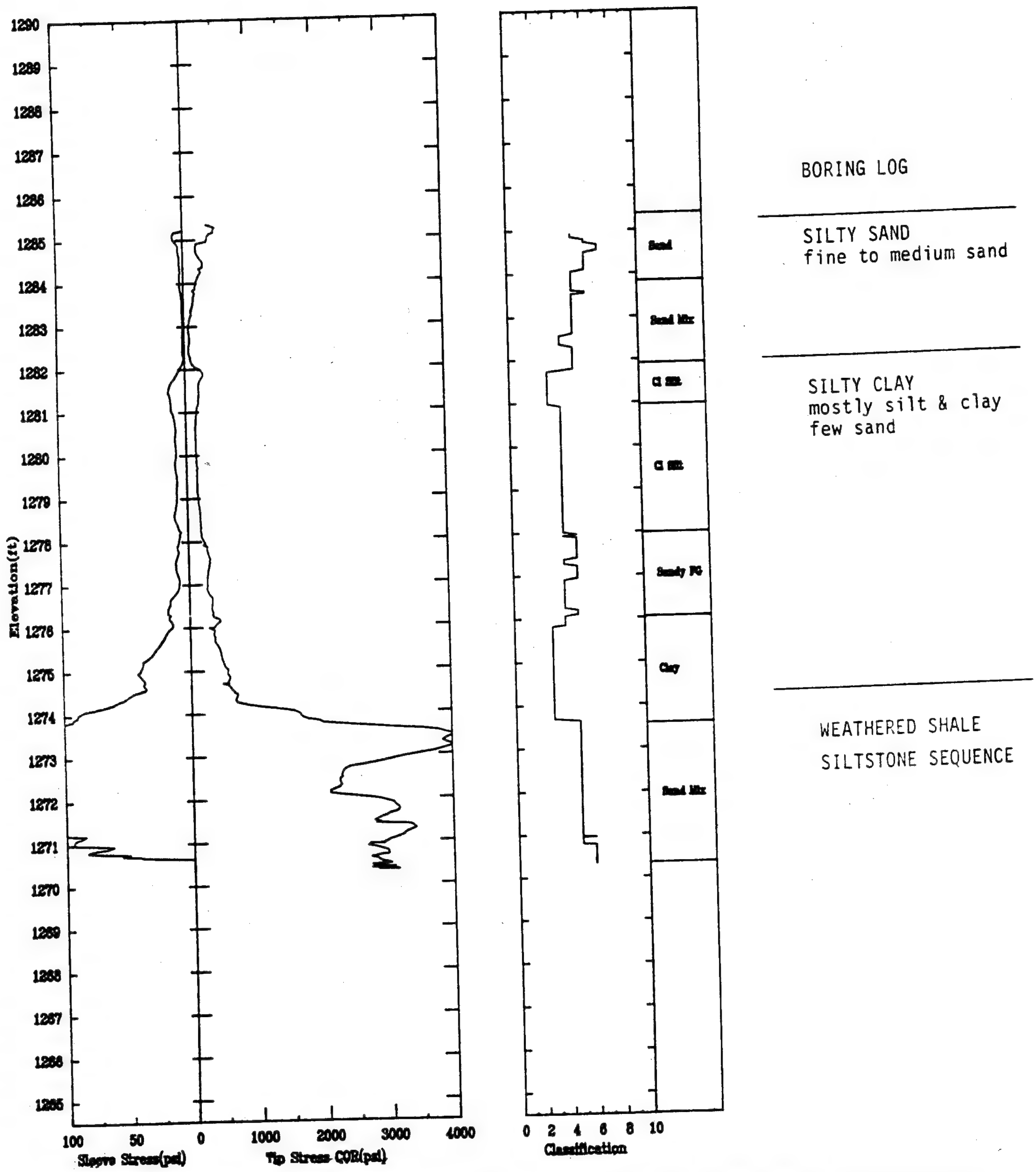


Figure 8. Comparison Plot Showing CPT Determined Soil Stratigraphy and the Soil Stratigraphy Determined by Borehole Logging.

workstation (TECHBASE® and visualization computer) located in ARA's mobile laboratory. Site feature information was digitized and imported in a similar manner.

Some trial statistical model runs were made to obtain satisfactory grid spacing, bounds, and search statistics. Advanced Visualization Systems, Inc.'s (AVS) scientific visualization package was used to display the model results and judge the quality of the data and statistics used. ARA developed a visualization program for geologic site characterization (GEOVIS) using standard AVS routines. Capabilities included cone/drill hole representation, surface and subsurface features, volume bounds, isosurfaces, horizontal slicing, axes, and labeling.

Hard copy of the results was not available in the field, but screen demonstrations for the Fuel Purge Area and North Tank Area were made. After initial debugging of the data processing sequence, visualization of the LIF-CPT data was performed within two to three days after acquisition. All aspects of visualization mentioned above (slicing, isosurfaces, etc.) were performed. Digitization of site features such as edge of pavement, buildings, etc. required additional time. This was the first demonstration of visualization of cone penetrometer data in the field performed outside the WES group.

Two types of presentation graphics were commonly created to assist with the site interpretation. These were isosurfaces, which show all volumes that have the same concentration level or above, and horizontal slices, which show concentration contours at a given elevation. Typical examples of these figures are shown in Figure 9 though 10. These figure types will be used as necessary in the site assessment section to present the detailed data obtained during the demonstration and testing program. These figures are highly useful in interpreting the four-dimensional data that was obtained during the demonstration and testing program. For both of these figure types, the color scale presented in Figure 11 was used. This color scale is based on the logarithm of the LIF values with 4 (LIF = 10,000 counts) being red and 2 (LIF = 100 counts) being green as shown in the figure. In addition, the green lines throughout the figure represent LIF-CPT locations.

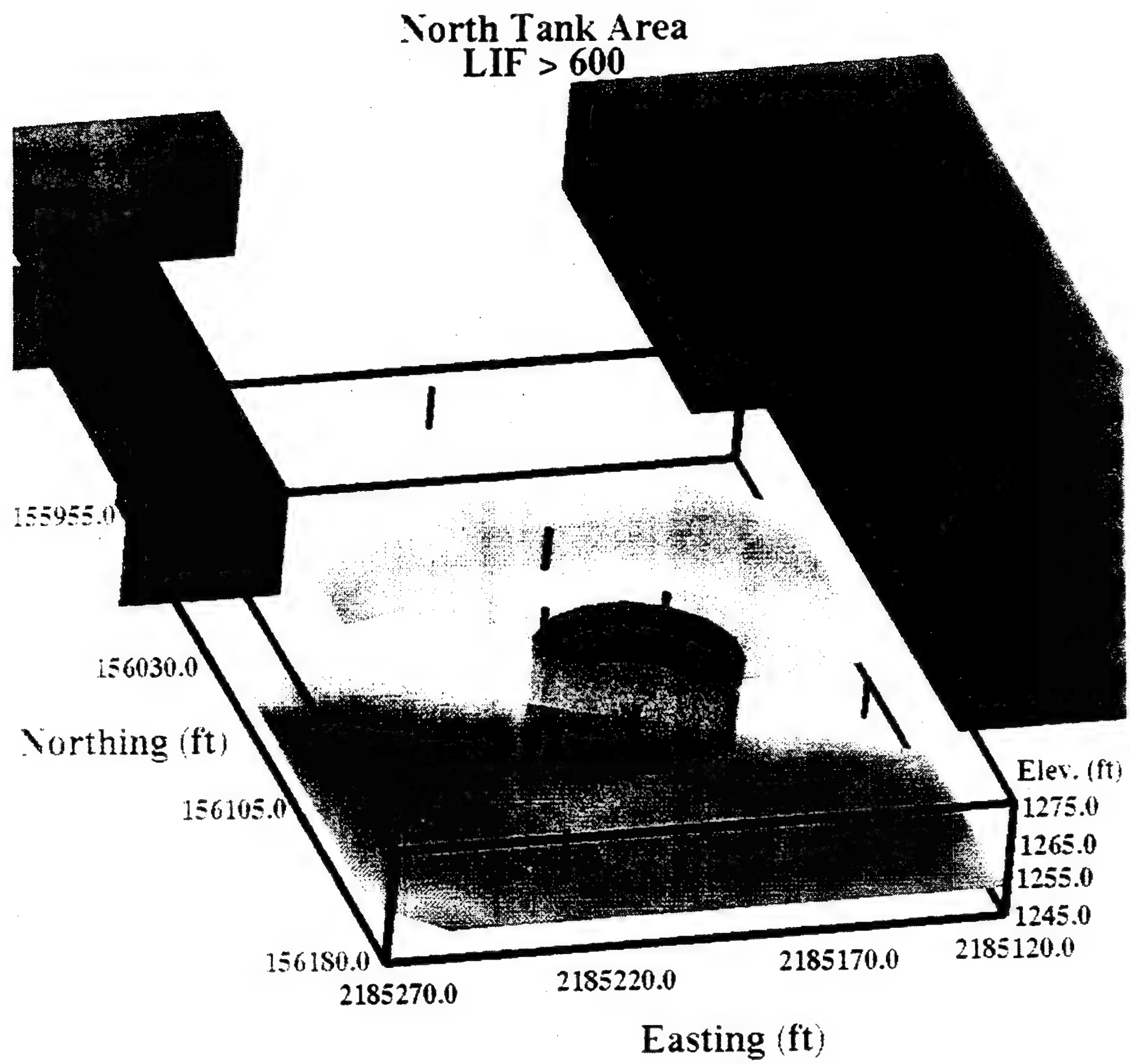


Figure 9. Example Isosurface from the North Tank Area Showing LIF Values Above 600.

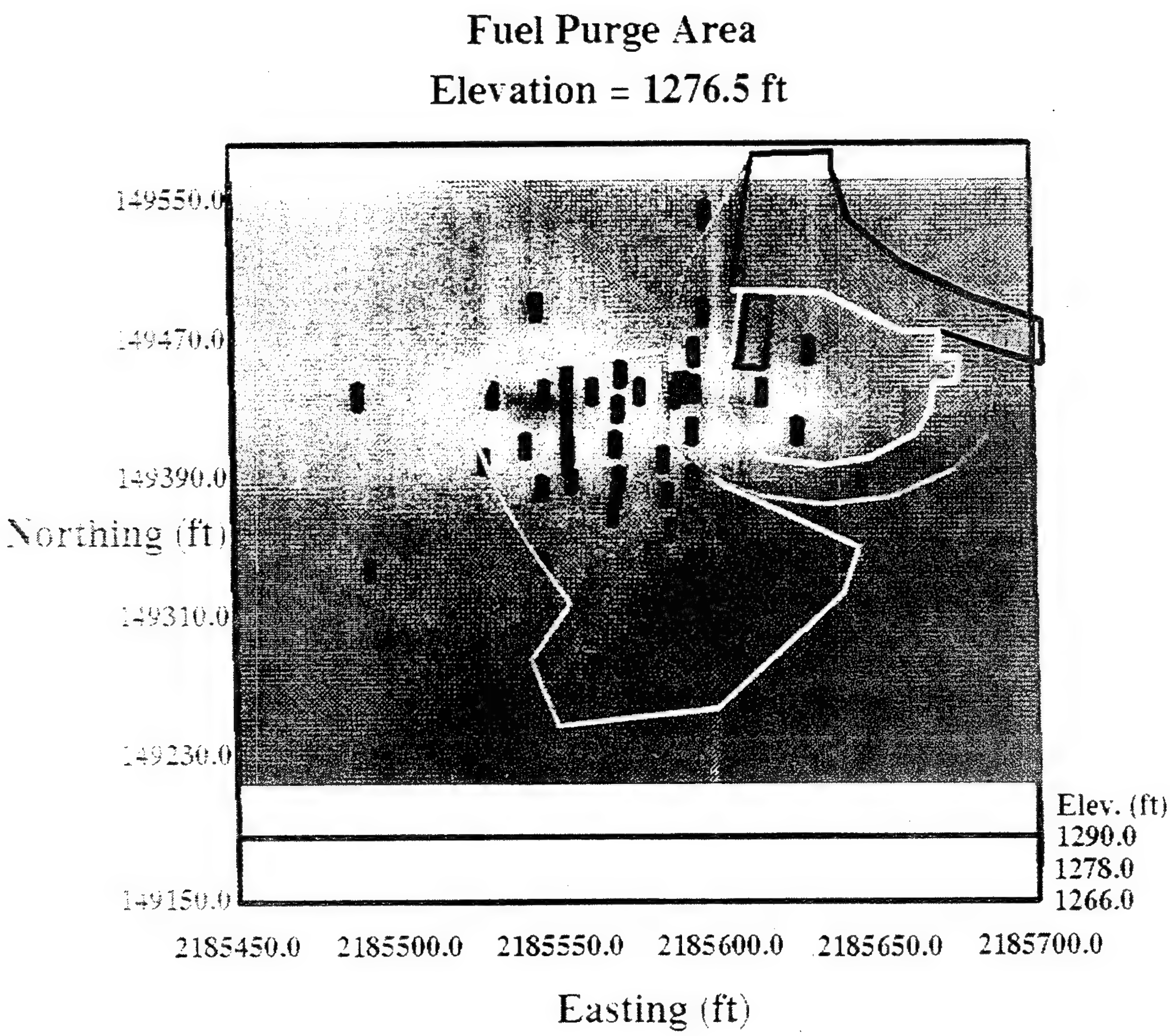


Figure 10. Example Horizontal Slice from Fuel Purge Area at an Elevation of 1276.5 Feet Showing Contamination Zones.

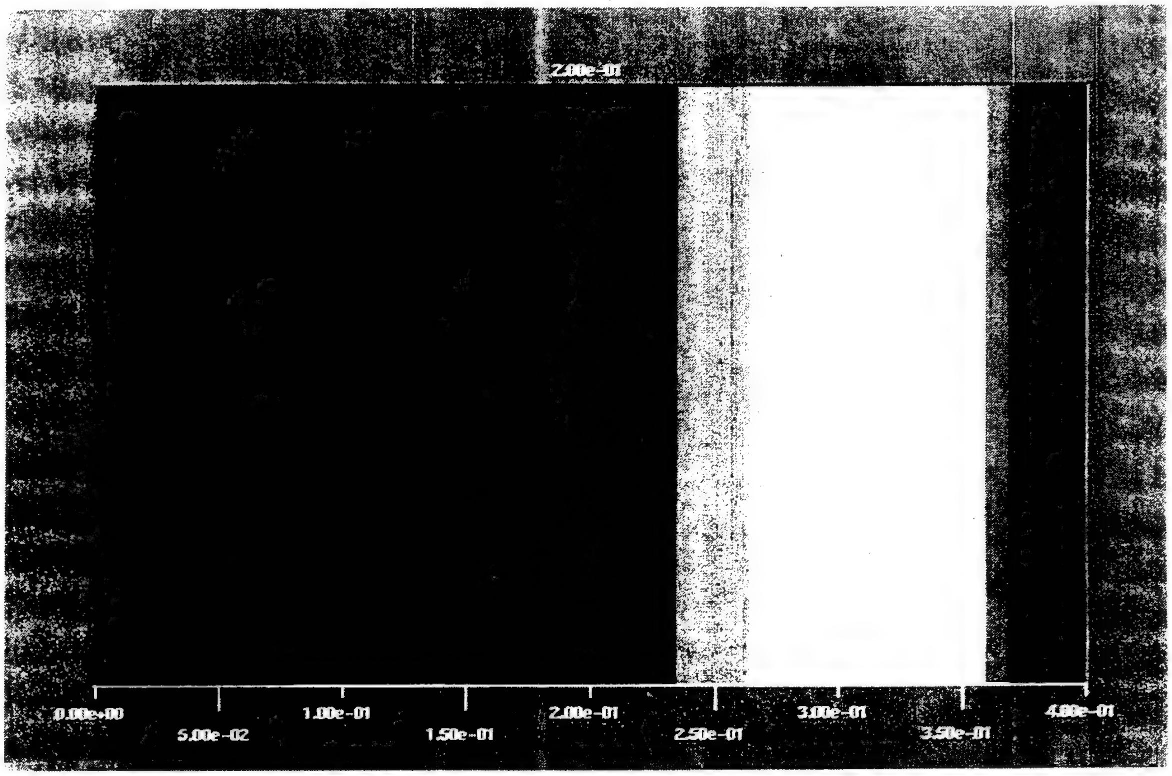


Figure 11. Color Map for All Isosurfaces and Horizontal Slices Generated During the Project.

SECTION IV

INDIVIDUAL SITE ASSESSMENTS

A. INTRODUCTION

This section presents a site analysis for each of the seven individual sites that were characterized during the 30-day demonstration at Tinker AFB. Emphasis is placed on the Fuel Purge Area since a large percentage of the field work was performed at this site, although each of the other sites are discussed individually. Each site analysis presents a brief background concerning contamination that is known to be present based on previous work, or contamination that is suspected based on previous site activities. Following this background discussion, the approach taken to characterize the site is presented. This approach is either followed by or incorporated into the results that were obtained at the site.

B. NORTH TANK AREA

1. Background

As shown in Figure 12, the North Tank Area is focussed on USTs located beneath a grassy area. The main UST of concern consisted of a 235,000-gallon concrete cylinder, approximately 50 feet in diameter and 22 feet deep, which had been used for storage of fuel oil since the 1940s. A 16-foot long by 18-foot wide buried pump station adjacent to the north wall of the tank is not shown on the site plan. As revealed by three monitoring wells installed during a UST investigation, the fuel oil UST (UST 3404) was discovered to be leaking in 1985. Subsequent recovery and monitoring wells installed around the fuel oil UST have been used to remove over 6,000 gallons of fuel oil. The fuel oil UST 3404 was cleaned, sealed and abandoned in place in June, 1992. Probable points of release at the base of the tank and at mid-level were identified during Tinker AFB inspections during the abandonment.

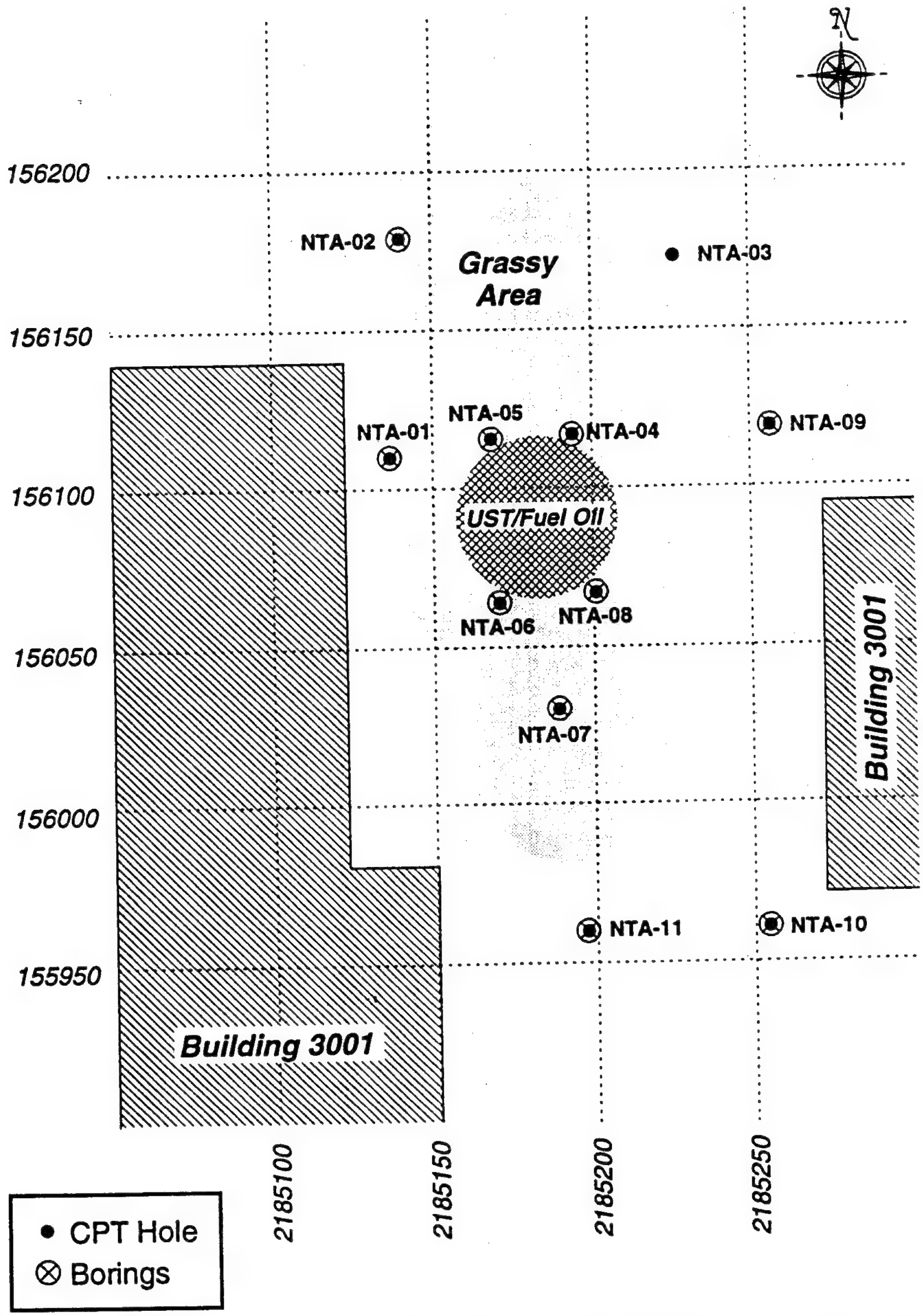


Figure 12. Site Map of the North Tank Area Showing Underground Storage Tank.

Three other USTs (not shown) exist in the grassy area, which may have contributed fuel contaminants as well: a 13,000-gallon Mogas UST (UST 3405) that was abandoned in 1985, a 20,000-gallon diesel fuel UST (UST 3401) located in the southern end of the grassy island, and a 1,200 waste oil UST (removed in 1992).

Fuel oil contamination of soil has been observed to extend from 12 to about 35 feet deep in the vicinity of UST 3404. Analysis of available subsurface data by Tinker AFB personnel and Battelle indicate that shallow groundwater flow is complicated by the possible presence of two distinct perched water-bearing zones within the upper 40 feet. Fill zones surrounding the fuel oil UST, in addition to utility trenches or improperly constructed monitoring wells, may alter the normal flow conditions by enhancing infiltration and possibly creating hydraulic conduits.

2. Approach and Results

In order to aid in characterizing the horizontal extent of residual fuel oil contamination, LIF-CPT profiling and sampling by CPT and drilling was performed at 11 locations during the demonstration program. Since soil contamination and groundwater were known to reside at depths greater than the anticipated refusal depth (about 12 feet), sampling was mainly achieved by drilling. CPT sampling was concentrated at locations within the fill materials. Soil between 12 to 17 feet and groundwater infiltrating the open drill holes was sampled and analyzed for BTEX, TPH, and VOCs.

After obtaining a background LIF signal in the first three push locations (NTA-01, -02 and -03), the layout was altered to allow pushes in the fill adjacent to the fuel oil UST. A site that was suspected of possessing easily penetrable fill with zones of residual fuel contamination was chosen; this situation would allow demonstration of the LIF probe. Results from this location confirmed the presence of petrochemical contamination from a depth of 13 feet to the end of the sounding at a depth of 21.4 feet, as shown in Figure 4. Analytical laboratory testing of samples obtained at this location confirm that fuel-type contamination was present. Additional contamination was indicated at other locations within the fill (e.g. NTA-05 and 06). WTMs were obtained from NTA-04, -05 and -06 at a depth of 12.5 to 13 feet and are displayed in Figures 13 through 15. Although the WTMs from NTA-04 and -05 are consistent, the WTM from NTA-06 has a longer peak wavelength. This indicates that the contamination at NTA-06 is possibly chemically different than those seen on

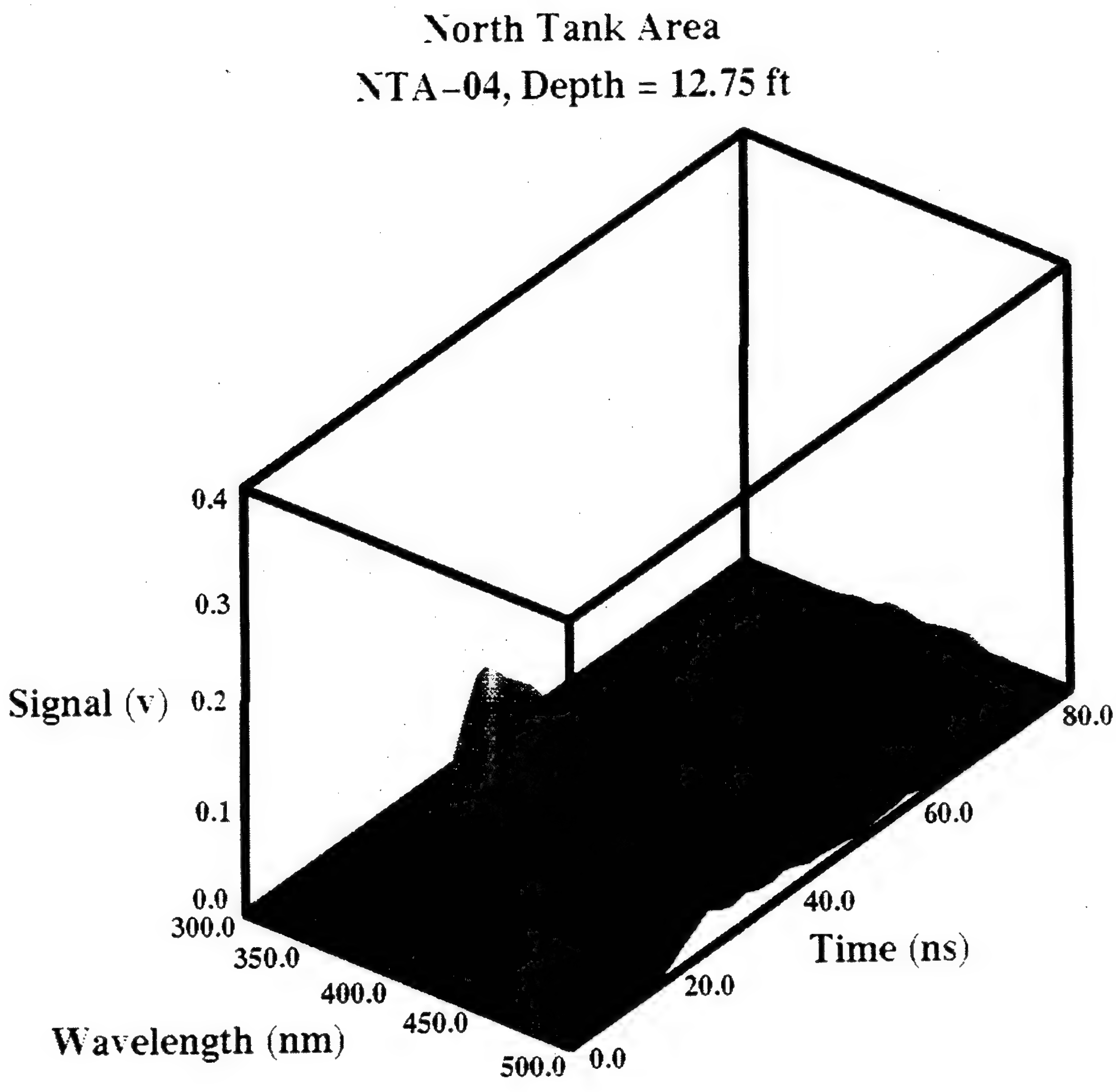


Figure 13. WTM from NTA-04 at a Depth of 12.75 ft Showing Large Responses from 360 to 400 nm.

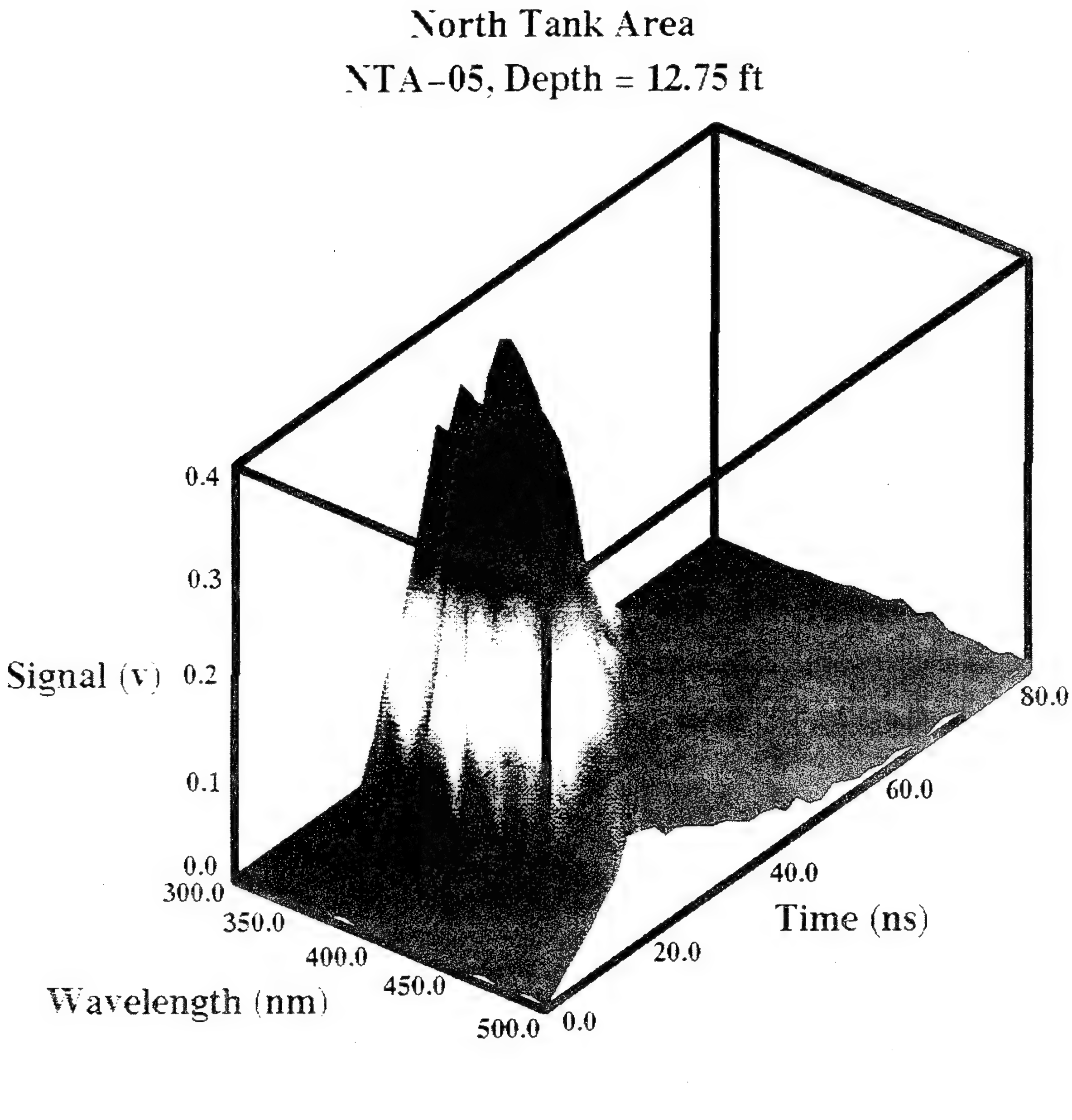


Figure 14. WTM from NTA-05 at a Depth of 12.75 ft Showing Large Responses from 360 to 400 nm.

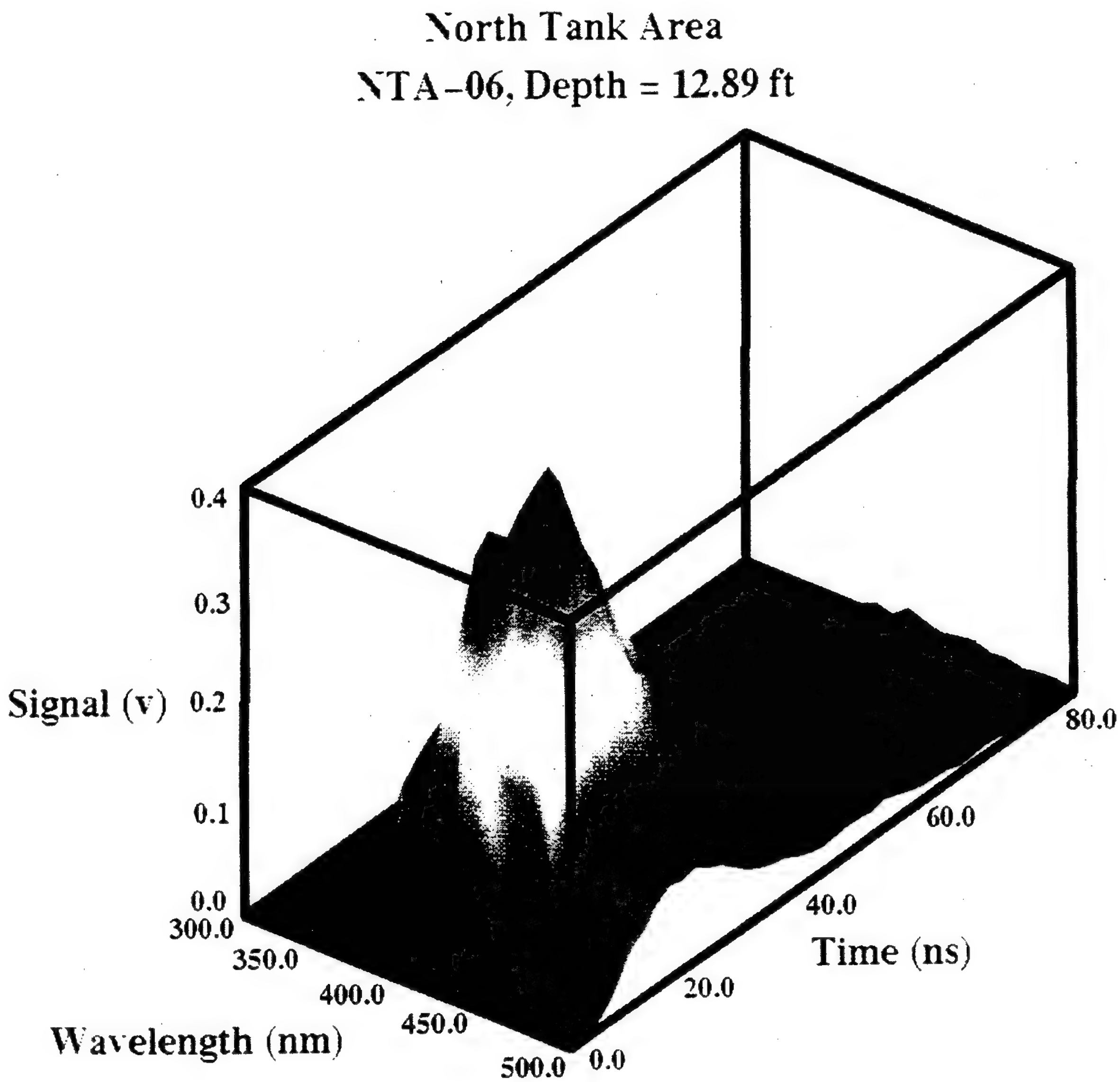


Figure 15. WTM from NTA-06 at a Depth of 12.89 Feet Showing Responses from 340 to 500 nm.

the north side of the UST. This difference is not present, however, in the comparisons of the measured waveform decay time histories versus depth. In Figure 16, the waveforms from NTA-04 have essentially the same shape as those present in the waveforms from NTA-06 (i.e. Figure 17).

Onsite scientific visualization was performed for the North Tank Area LIF results. These results assisted in the understanding of the contamination zones present at the site. At an elevation of 1261.5 feet low levels of contamination are evident on the south side of the tank, as shown in Figure 18, but at an elevation of 1252 feet the contamination is concentrated to the north side of the UST with some contamination on the south side (Figure 19). The contamination zones are also shown by isosurfaces of the zone of LIF response greater than 800 (Figure 20) and 600 (Figure 21). Once again, higher contamination is seen on only the north side of the tank, while lower contamination is seen surrounding the entire tank. Estimates of the TPH are uncertain since the LIF calibration was performed using jet fuels and not fuel oil, however, it is estimated that the TPH values shown in Figure 20 and 21 are approximately 800 and 600 respectively. The visualization procedure involved digitizing the adjacent building outlines and the perimeter of the cylindrical fuel oil UST 3404. Although the stations were deemed to have a fairly good spatial distribution, the fact that deep penetrations were only near the UST tended to bias the three-dimensional statistical model results. As only those penetrations conducted next to the old UST extended below 12 feet, the model may have extrapolated the LIF hot zone beyond the actual limits.

Logging of soil cores indicated that residual soils, consisting of sandy clays, occurring to a depth of about 10 to 14 feet across the site. The CPT-based soil stratigraphy generally agreed with the borings stratigraphy developed from the drilling program as shown in Figure 4. The residual nature of the soils tended to indicate sandier soil types for the computer-generated soil profiles when compared to the geologist logs. These effects were not confirmed by index soil testing such as USCG grain size analysis. If such effects are deemed significant they can be compensated for by developing a site-specific CPT soil classification system.

The CPT refusal provided the precise elevation of the upper surface of the weathered sandstone bed. Disregarding the geometry of the filled area located adjacent to the USTs a fairly uniform 1 percent gradient to the north was present, suggesting a local northerly dip for the sandstone layer as shown in Figure 22. The CPT refusal depths also indicate that the thickness of unconsolidated

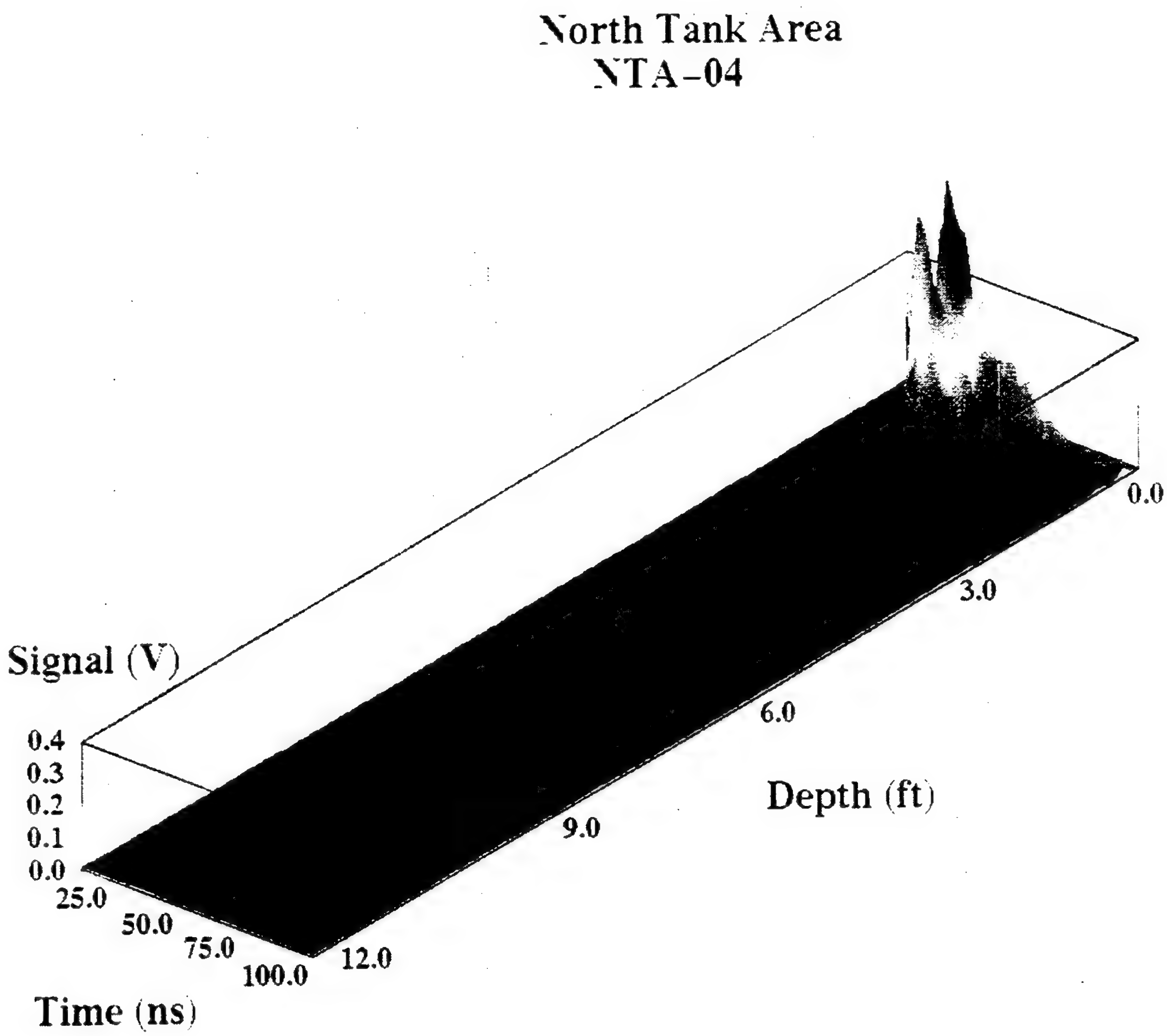


Figure 16. Waveform Time Decays Versus Depth for NTA-04 Showing a Time Decay of Approximately 50 ns.

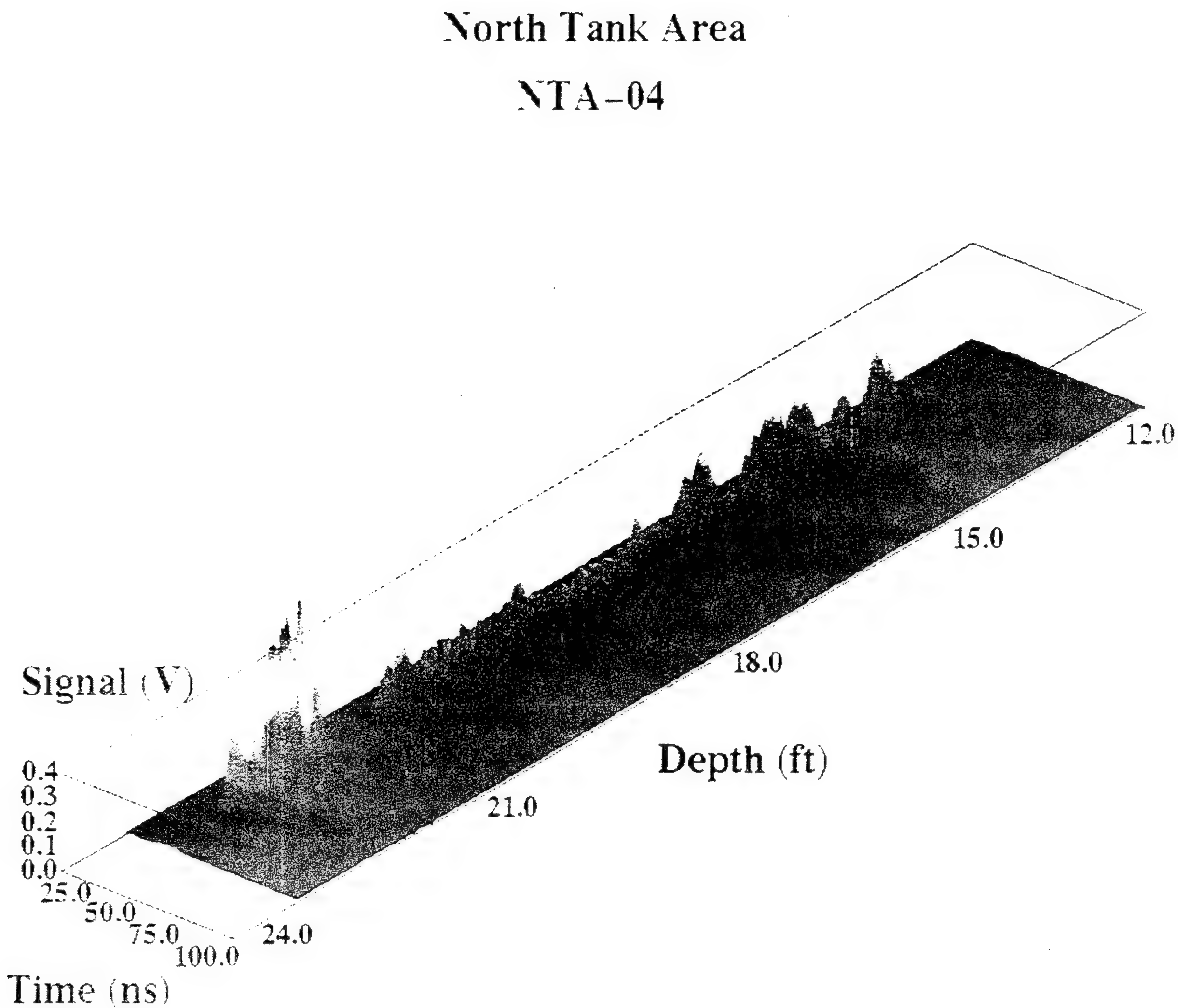


Figure 16. Waveform Time Decays Versus Depth for NTA-04 Showing a Time Decay of Approximately 50 ns (Concluded).

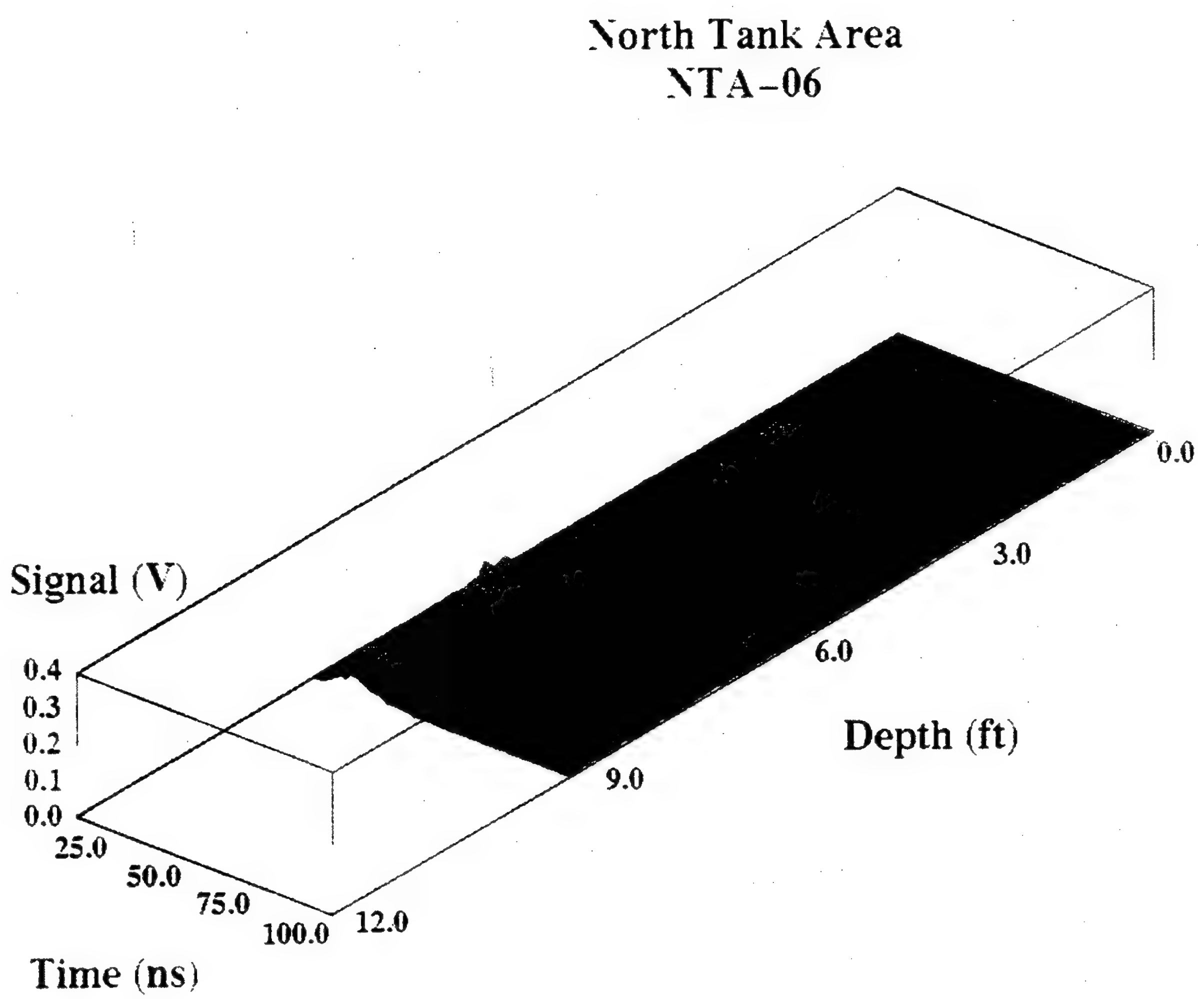


Figure 17. Waveform Time Decay Versus Depth for NTA-06 Showing a Time Decay of Approximately 50 ns.

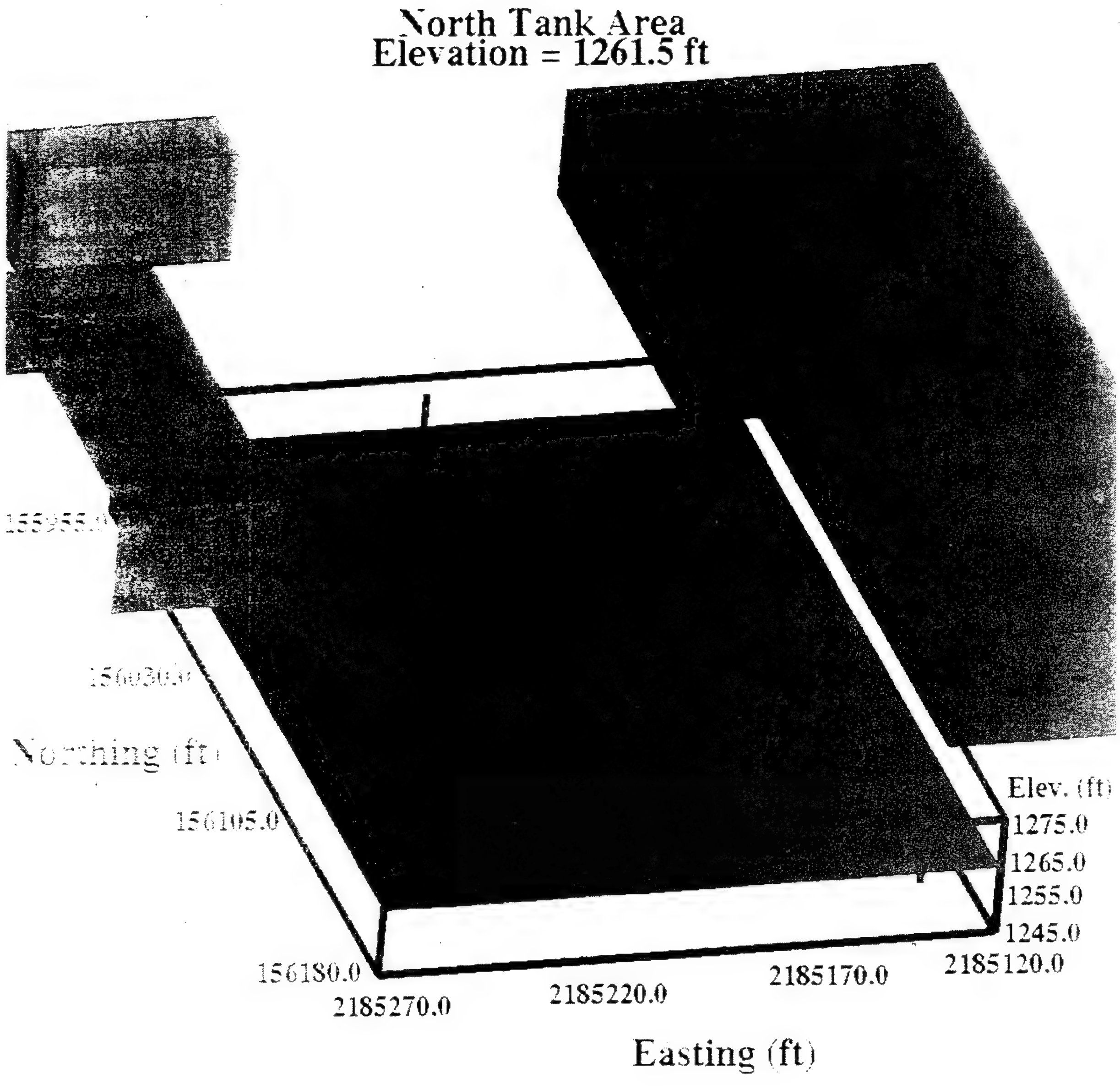


Figure 18. Horizontal Slice of NTA at an Elevation of 1261.5 Feet Showing Contamination on the South Side of the UST.

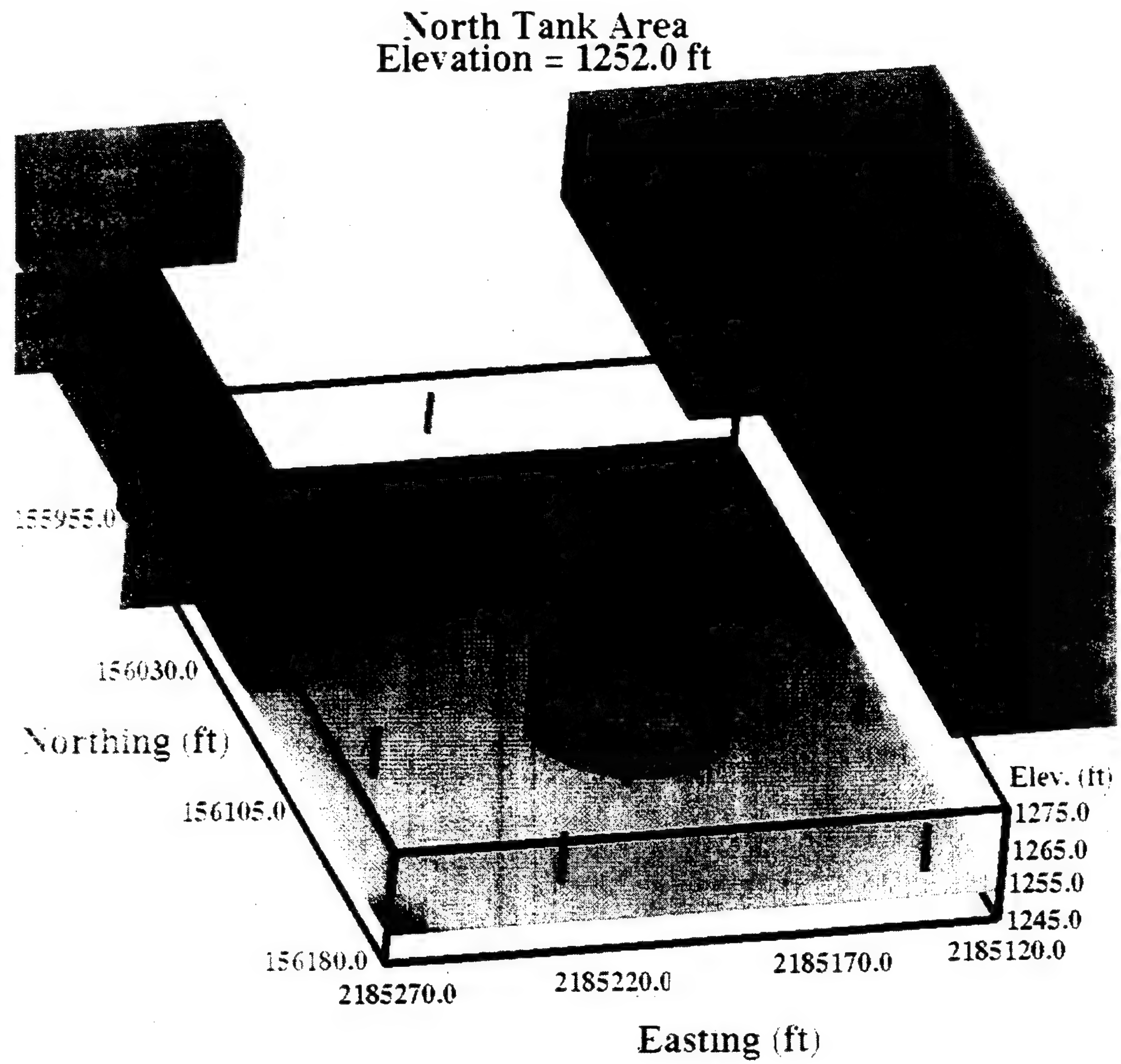


Figure 19. Horizontal Slice of NTA at an Elevation of 1252.0 Feet Showing Contamination Mostly on the North Side of the UST.

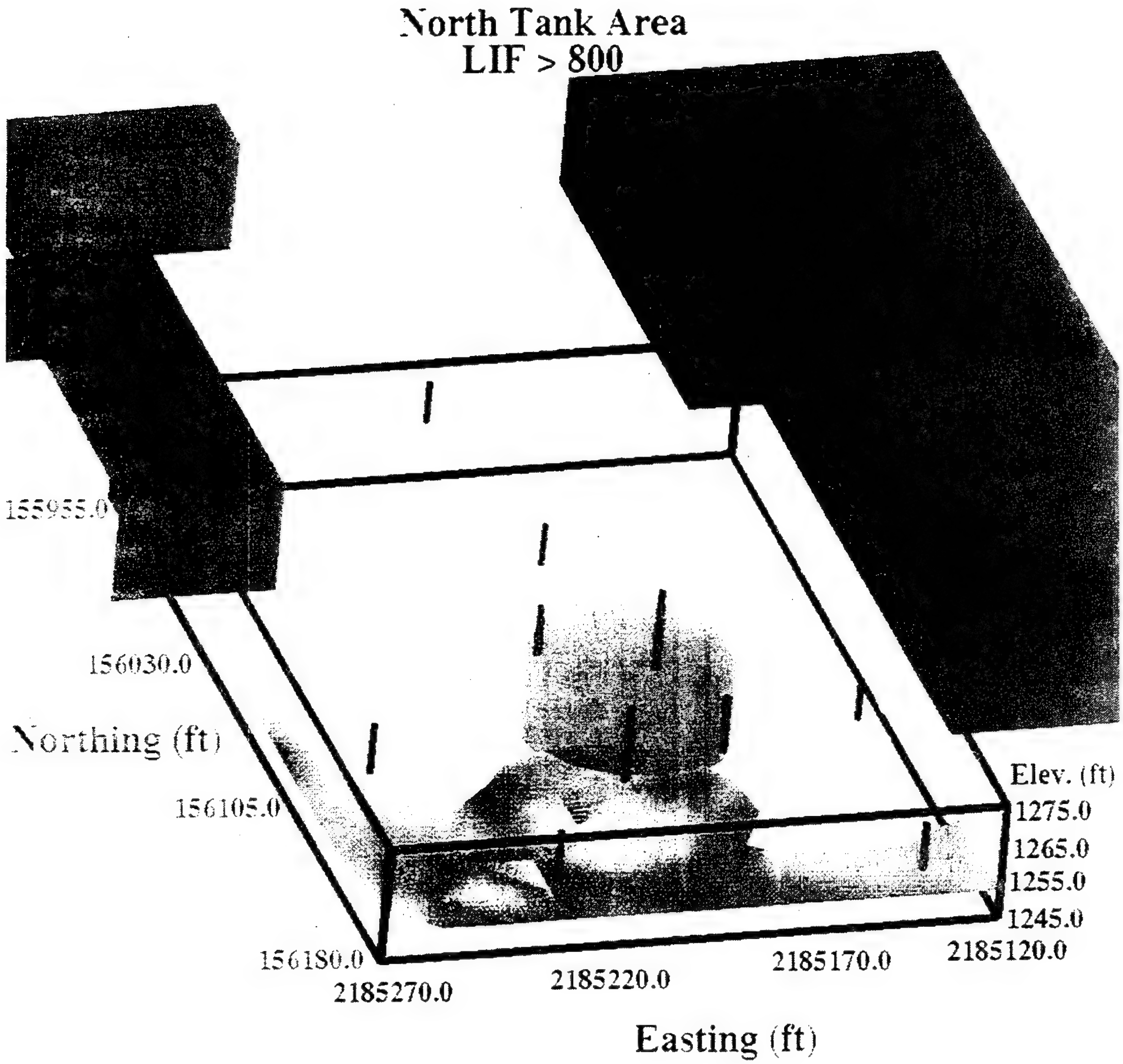


Figure 20. Isosurface of the NTA Showing Volume of Soil Exhibiting an LIF Response Greater than 800.

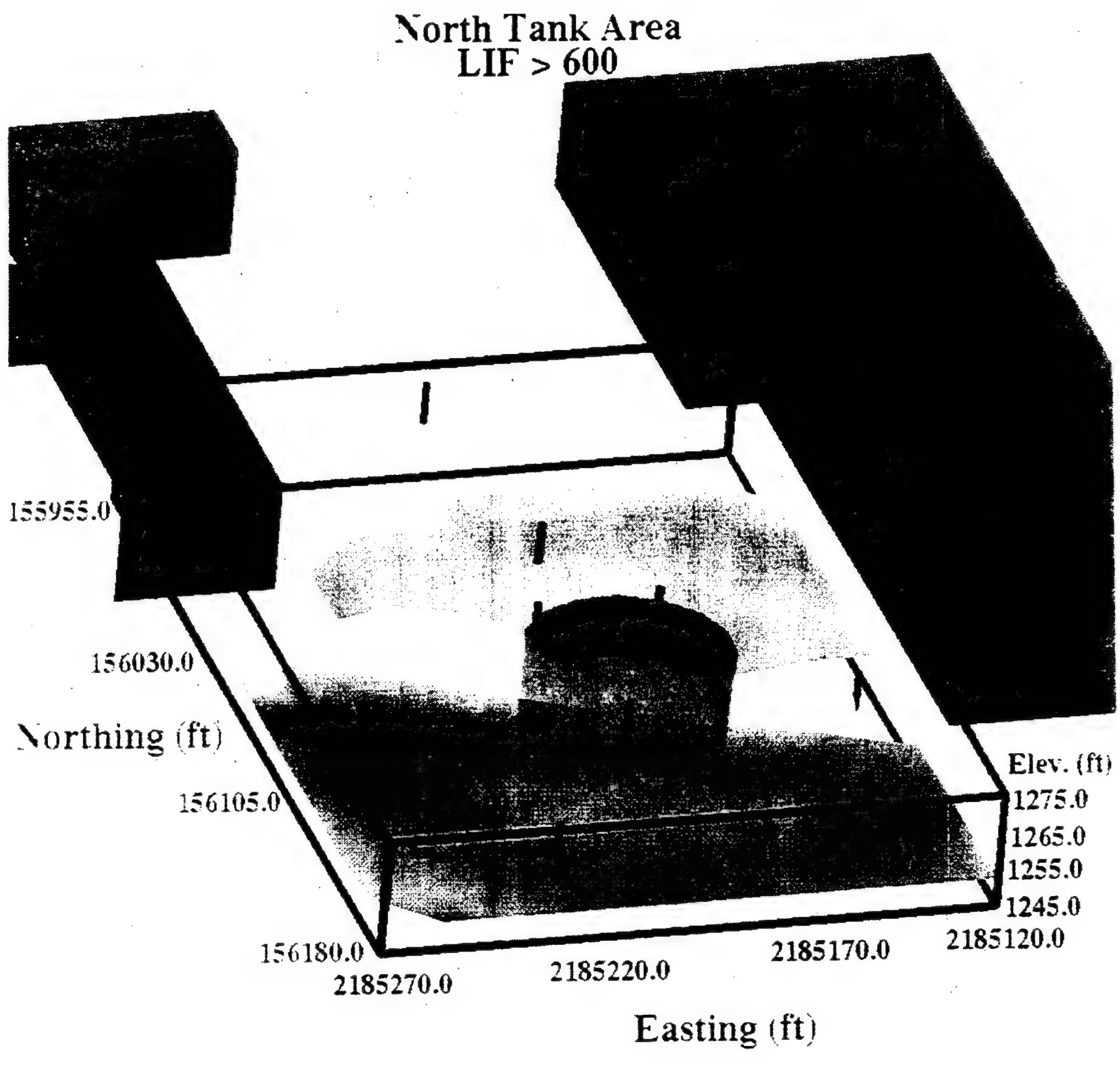


Figure 21. Isosurface of the NTA Showing Volume of Soil Exhibiting an LIF Response Greater than 600.

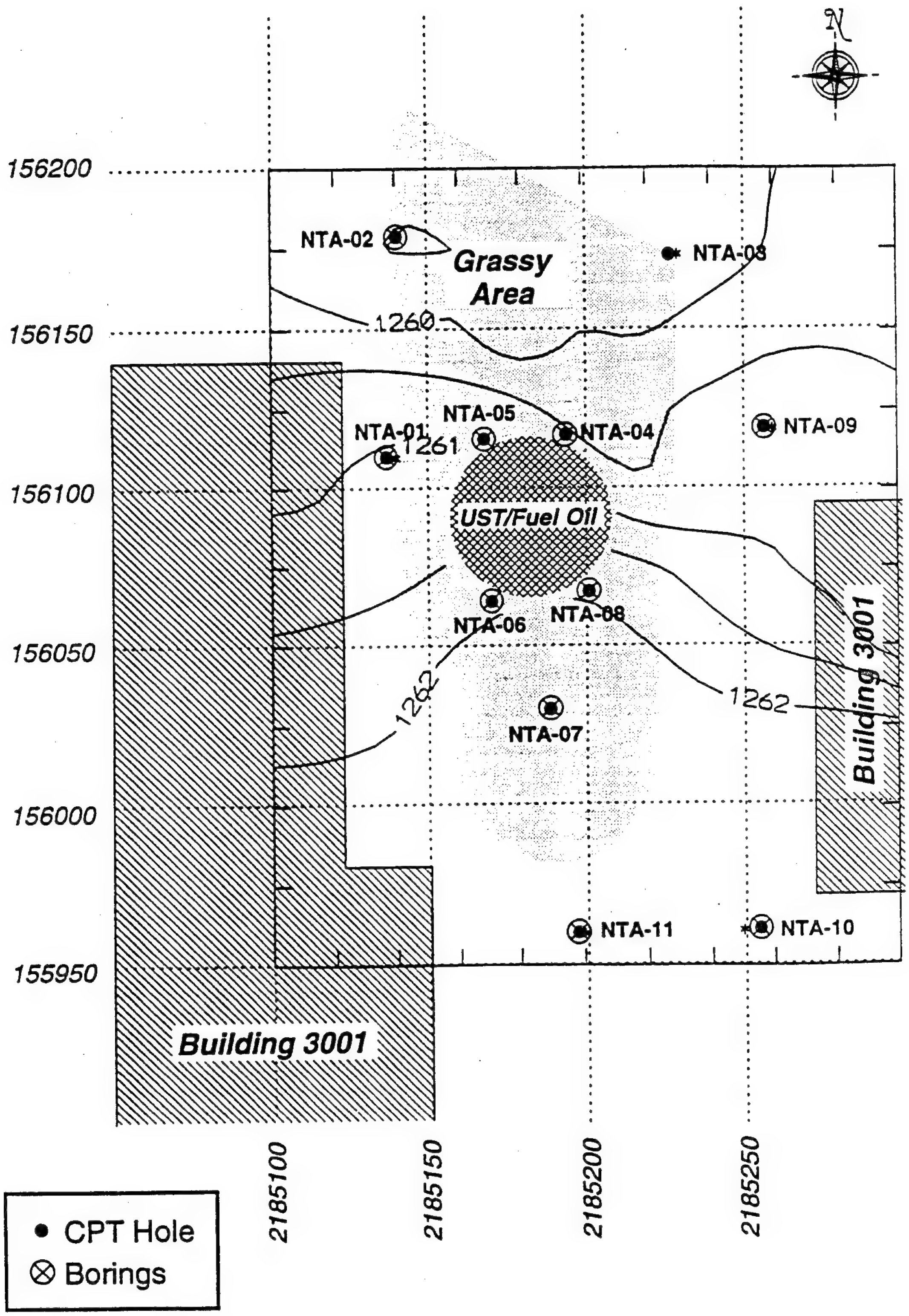


Figure 22. Contours of the CPT Refusal Elevations, Which Correspond to the Top of the Sandstone for NTA.

material and the depth to consolidated bedrock (sandstone) in undisturbed areas is about 5 to 10 feet deeper than previously thought.

The deepest LIF-CPT push were located in the projected excavation zone for the fuel oil UST confirming that filled materials surround the UST. The CPT refusal surface suggested steep excavation walls were used during the tank construction. Furthermore, the maximum penetration depth at the North Tank Area, 23.15 feet at NTA-04, is consistent with the projected depth for the tank foundation.

Groundwater table elevations determined from water level measurements made in the open drill holes on September 18, 1992 indicate that the groundwater table lies just below the top of the refusal surface, especially in the southern portion of the site.

Chemical results for the North Tank Area soil and groundwater support the LIF results, and prior estimates of product thickness and chemical evidence of gross fuel-contamination in the vicinity of the fuel oil tank. Tables 5 and 6 present the onsite field GC results obtained on samples from NTA. The results from ANALAB, the independent laboratory, are presented in Tables 7 and 8. Although all measurements are significant, the TPH results for both soil and water provide the best data for mapping due to the practical range and distribution of the data. Nevertheless, soil and water TPH distributions both suggested fuel-contamination is generally greater to the south of the tank than to the north, as shown by Figures 23 and 24. As a general rule, the soil TPH tended to be an order of magnitude higher than the water TPH.

BTEX and chlorinated compounds are also detected in the soil and groundwater. Fuel oil generally has low BTEX; recovered fuel oil was measured to contain 5, 74, 214, and 845 mg/l for each of the benzene, toluene, ethyl benzene and xylenes, respectively (5). Water samples were generally diluted by ANALAB Corp., so that the necessary sensitivity in VC detection limits was not available for samples with high TPH values. However, detectable quantities of benzene were measured in the groundwater for NTA-07 and NTA-09. Soil samples had adequate detection limits for both ANALAB and the onsite GC results. Maximum values of 0.183, 0.542, 1.223, and 2.274 mg/kg were obtained for the BTEX parameters at NTA-04 (14 to 14.5 ft), respectively, using the onsite GC.

TABLE 5. ONSITE ANALYSIS OF SOIL SAMPLES FROM NORTH TANK AREA.

Soil Samples

Location		NTA-04	NTA-04	NTA-04	NTA-04	NTA-B05	NTA-B04	NTA-B01	NTA-B10	NTA-B11
Depth Interval From	(ft)	9	14	14.5	15	13	11.5	13	13	13
To	(ft)	10.3	14.5	15	15.5	14	12.5	14	14	14
Benzene	(mg/kg)	<0.020	0.183	<0.020	<0.020	0.027	<0.020	<0.020	<0.020	<0.020
Toluene	(mg/kg)	<0.020	0.542	0.050	<0.020	0.179	0.030	<0.020	<0.020	<0.020
Ethyl Benzene	(mg/kg)	<0.020	1.223	0.092	<0.020	0.311	0.093	0.034	<0.020	<0.020
M-Xylene	(mg/kg)	<0.020	2.274	0.127	<0.020	0.677	0.130	0.026	<0.020	<0.020
Naphthalene	(mg/kg)	<0.020	5.978	3.316	0.318	1.875	3.570	3.329	0.132	0.042
2-Methyl Naphthalene	(mg/kg)	<0.020	0.382	1.688	0.727	0.184	0.828	2.459	0.159	<0.020

TABLE 6. ONSITE ANALYSIS OF WATER SAMPLES FROM NORTH TANK AREA.

Water Samples

Location		NTA-B05	NTA-B10
Depth below ground surface, ft		12	12
Benzene	(ug/L)	<20	<20
Toluene	(ug/L)	<20	<20
Ethyl Benzene	(ug/L)	<20	<20
M-Xylene	(ug/L)	<20	<20
Naphthalene	(ug/L)	86.006	<20
2-Methyl Naphthalene	(ug/L)	163.737	<20

TABLE 7. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM NORTH TANK AREA.

Soil Samples

Location			NTA-B01	NTA-B02	NTA-04	NTA-04	NTA-04	NTA-B05	NTA-B06	NTA-B07	NTA-B08	NTA-B09	NTA-B10	NTA-B11
Depth Interval	From	ft	13	12	9.3	15	13	13	12	13	13	13	13	13
	To	ft	14	14	10.9	15.5	16.8	14	17	16	15	15	14	14
Date Sampled			9/17/92	9/17/92	9/3/92	9/3/92	9/3/92	9/17/92	9/17/92	9/17/92	9/17/92	9/18/92	9/17/92	9/18/92
Total Petroleum Hydrocarbon		mg/kg	380	22	26	N/A	26000	4600	25000	9600	35000	<10	22	15
Benzene		mg/kg	<0.005	<0.005	<0.005	<0.005	<0.025	<0.005	0.044	<0.005	<0.005	<0.005	<0.005	<0.005
Toluene		mg/kg	<0.005	<0.005	0.014	<0.005	<0.025	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ethyl Benzene		mg/kg	<0.005	<0.005	<0.005	<0.005	0.29	<0.005	0.39	0.042	<0.005	<0.005	<0.005	<0.005
Xylenes		mg/kg	<0.005	<0.005	<0.005	<0.005	0.25	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Naphthalene (HPLC)		mg/kg	<0.05	<0.05	<0.05	N/A	N/A	<0.05	0.9	2	<0.05	<0.05	<0.05	<0.05
Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	5.3	<1	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (HPLC)		mg/kg	4	<0.05	<0.05	N/A	9	10	<0.05	<0.05	22	<0.05	<0.05	<0.05
2-Me-Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	N/A	1.7	N/A	N/A	N/A	N/A	N/A	N/A
Phenanthrene		mg/kg	N/A	N/A	N/A	N/A	5.6	2.5	N/A	N/A	N/A	N/A	N/A	N/A
Fluoranthene		mg/kg	N/A	N/A	N/A	N/A	<1	1.5	N/A	N/A	N/A	N/A	N/A	N/A
Total Phenols		mg/kg	<1	<1	<1	N/A	<2	<5	<1	<5	<5	<0.02	<1	<0.02
Chlorobenzene		mg/kg	<0.005	<0.005	<0.005	<0.005	0.03	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Tetrachloroethene		mg/kg	<0.005	<0.005	<0.005	<0.005	<0.025	<0.005	<0.005	<0.005	0.014	<0.005	<0.005	<0.005
Trichloroethene		mg/kg	<0.005	<0.005	<0.005	<0.005	<0.025	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
trans-1,2-Dichloroethene		mg/kg	<0.005	<0.005	<0.005	<0.005	<0.025	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

TABLE 8. OFF-SITE ANALYSIS OF WATER SAMPLES FROM NORTH TANK AREA.

Water Samples

Location		NTA-B01	NTA-B02	NTA-B04	NTA-B05	NTA-B06	NTA-B07	NTA-B08	NTA-B09	NTA-B10	NTA-B11
Depth Below Ground Surface	ft	wt	wt	wt	wt	wt	wt	wt	wt	wt	wt
Date Sampled		9/18/92	9/18/92	9/16/92	9/16/92	9/17/92	9/17/92	9/16/92	9/18/92	9/18/92	9/18/92
Total Petroleum Hydrocarbon	mg/l	37	<10	2400	140	5100	1100	690	50	<10	<10
Benzene	ug/l	<50	<5	<500	<50	<500	14	<500	10	<5	<5
Toluene	ug/l	<50	<5	<500	<50	<500	<10	<500	<5	<5	<5
Ethyl Benzene	ug/l	<50	<5	<500	<50	<500	30	<500	6.9	<5	<5
Xylenes	ug/l	<50	<5	<500	<50	<500	<10	200	<5	<5	<5
Chlorobenzene	ug/l	<50	<5	<500	<50	<500	<10	<500	<5	<5	<5
Tetrachloroethene	ug/l	<50	6.3	<500	<50	<500	<10	<500	<5	<5	6.4
Trichloroethene	ug/l	<50	<5	<500	<50	<500	<10	<500	<5	34	<5
trans-1,2-Dichloroethene	ug/l	<50	55	<500	<50	<500	<10	<500	<5	11	33

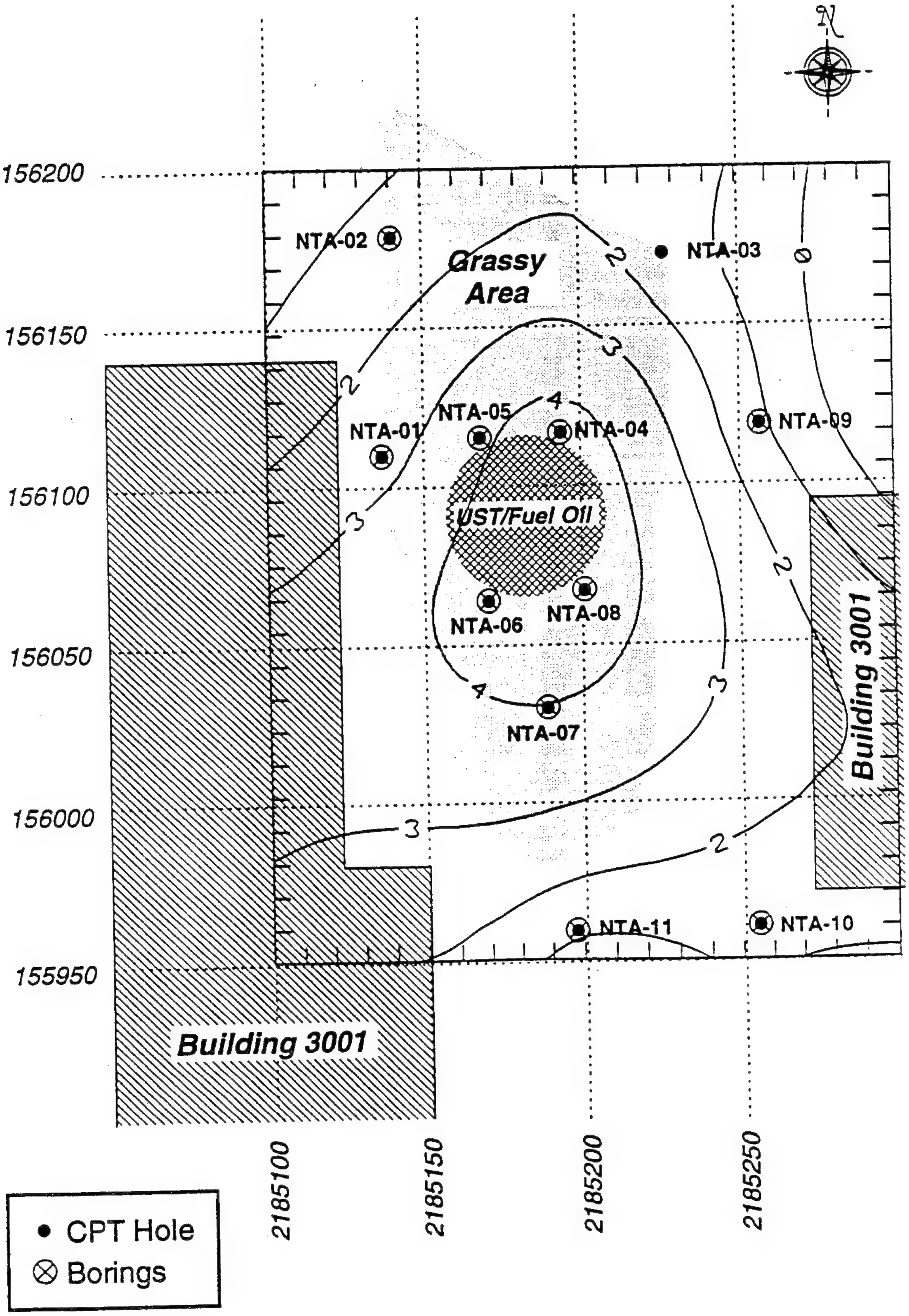


Figure 23. Contours of the Log of the Soil TPH Values for NTA at a Depth of 14 Feet.

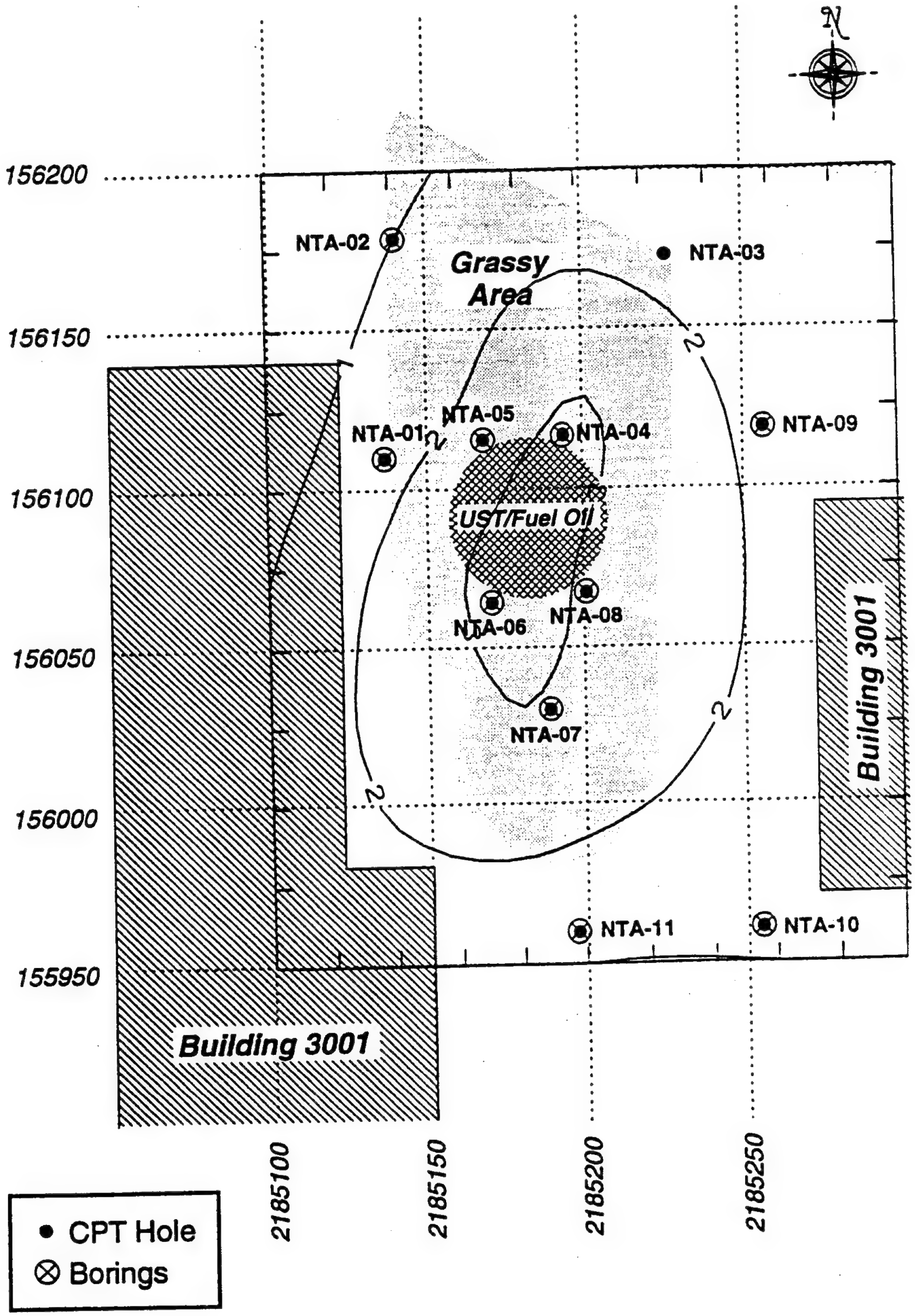


Figure 24. Contours of the Log of the Water TPH Values for NTA.

Using the GC/MS, some trace amounts of chlorinated VOCs, including tetrachloroethane, trichloroethene, and trans-1,2-dichloroethene, appeared to be present in most water samples. Tra ce amounts of chlorobenzene and tetrachloroethane were found in the soil samples as well. Some PAHs such as naphthalene, 2-methyl naphthalene, phenanthrene, and fluoranthene were detected in a GC/MS scan using a base/neutral extraction in a fuel-contaminated soil from NTA-04. This corroborated the LIF readings at NTA-04 which suggested naphthalene and related PAHs were present.

C. FUEL-PURGE AREA

1. Background

As shown in the site plan (Figure 24), the Fuel-Purge Area encompasses over 5 acres in the east central part of Tinker AFB. The active tarmac apron is located just to the north. A formal IRP investigation of the site has not been completed, thereby limiting the amount of data that is available. Several sources of fuel contamination are known to exist at the site as follows:

a.) Fuel hydrant system located 50 feet off the apron: Since 1990, JP-5 was transferred from the hydrant system to the fuel purge tanks. Prior to that, JP-4 was used.

b.) Two 25,000-gallon fuel purge USTs (USTs 2114 and 2115) and a drainage sump UST (UST 2117), both located near the pump shed (Building 2111): The purge tanks have held JP-5 since 1990. The sump UST contains drainage collected from spills occurring in the fuel pump shed via a gravity drain line.

c.) Waste fuel/oil above ground cylindrical tanks: Two groups of above ground cylindrical tanks are used for waste oil collection. One group consisting of two tanks directly connected, via a gravity drainage line, to the turnaround fuel dump facility. Both groups of tanks have berms constructed for Spill Prevention, Control and Countermeasure (SPCC) purposes.

d.) Waste fuel dump turnaround area: A report by Tinker AFB Directorate of Environmental Management[1] discusses the operation of the waste fuel dump site. In Figure 25, the turnaround area is shown in an expanded view, with both the old ramp location (circa 1975 to 1990) and the present ramp location (constructed 1990-1991). The waste fuel consisted of residual fuel left in the airplane tanks and occasionally spent fuel/solvents used in cleaning the tanks.

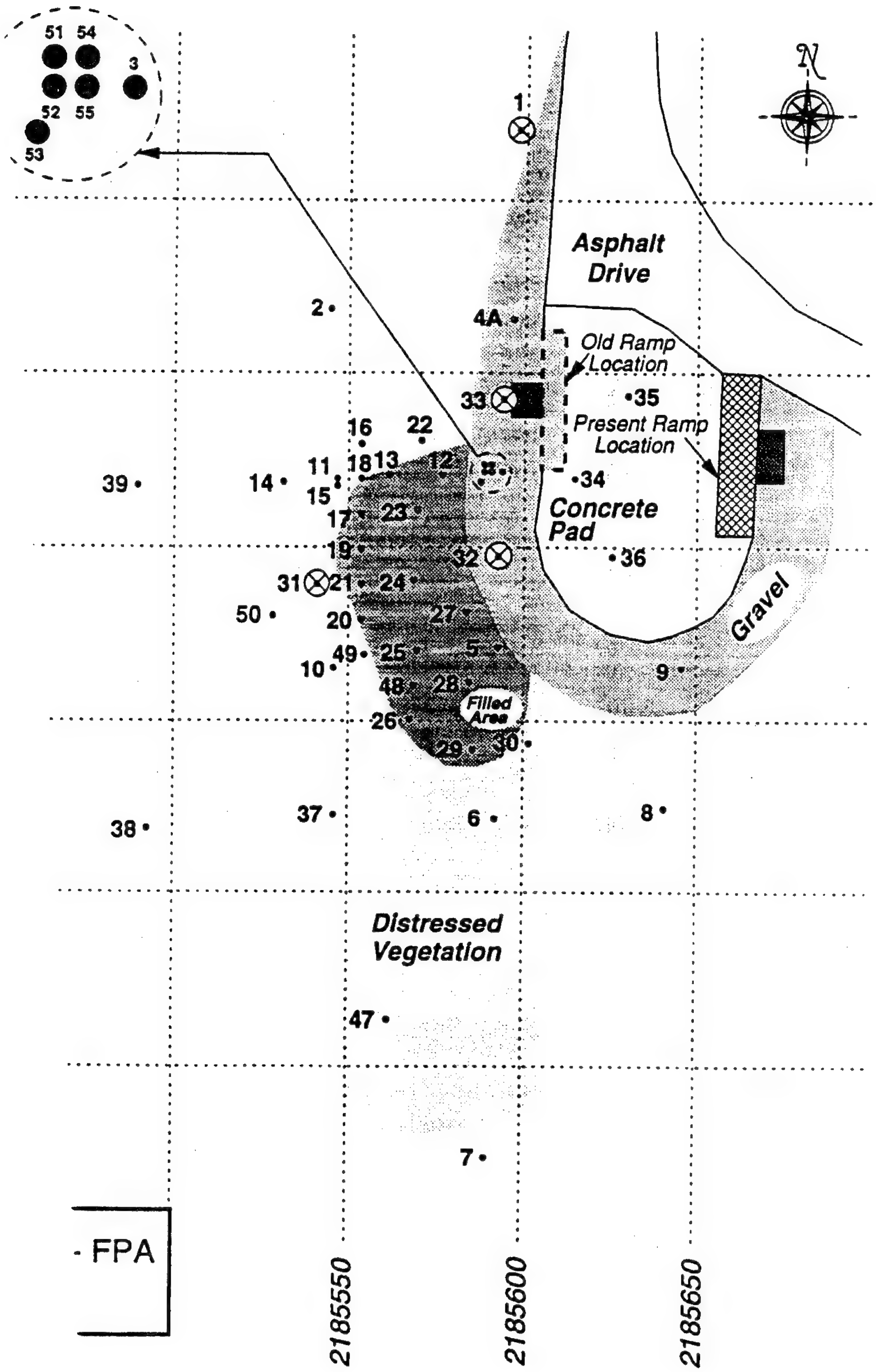
Fuel dumped at the turnaround is normally transported in bousers. Bousers are pulled from the tarmac using trucks, rolled onto the turnaround pad and onto the ramp. The ramp lies above a storage bunker that drains by gravity to the above ground tanks located 300 feet south. The old ramp was the site of spills around the bunker onto bare soils. Hand probing and TPH, BTEX and TCLP analyses were used to define the extent of soil contamination around the ramp. A volume of 2,820 cubic yards in a 100-foot by 50-foot area was determined to have TPH values in excess of 50 mg/kg (6); contamination was not indicated below 10 feet in most cases. About 350 cubic yards of grossly contaminated soils located beneath the bunker were reportedly excavated and disposed off-site during dismantling of the old facility. The new fuel turnaround dump facility was constructed with SPCC provisions, including concrete spill containment dikes around the bunker.

There have been several JP-4 and/or JP-5 spills documented for the Fuel-Purge Area within the last two years. In the spring of 1992, the purge tank area was the site of a JP-5 overflow to the sump tank. Approximately 20 cubic yards of soil were removed in the vicinity south of the purge USTs, roughly between stations FPA-40 and FPA-41 (Figure 26). Additionally, some minor spillage occurs on a fairly regular basis when bousers are parked along the circular drive area leading to the fuel dump turnaround pad. The cumulative effect of these drippings could have some impact.

As discussed below, site reconnaissance and LIF-CPT profiling revealed that a surface spill recently took place in an area located near sounding FPA-11 and FPA-12. The portion nearest to the gravel drive had been filled with a few inches of soil to reportedly cover a wet spongy area.

---

1 Tinker Air Force Base, Directorate of Environmental Management, Unpublished Report on Waste Fuel Dump Site, Prepared for AF by Leaman Harris, 1991.



Site Map of the Fuel-Purge Turnaround Area Showing Both Old and New

This covered area is surrounded by a larger area of distressed vegetation that extends about 150 feet to the south. Surface drainage is mostly directed to the south by a 1- to 2-percent slope.

Prior to this study, groundwater levels had not been investigated in the Fuel-Purge Area. Approximately 500 feet south of the turnaround, wells have been installed that indicate variable groundwater conditions (6). Heterogeneity in sand content allowing higher infiltration in places has been cited as possible mechanisms for the variability. A 780-foot deep water supply well (WS-22), located 50 feet north of the purge tanks, has been periodically tested.

Due to the release of waste fuel or purged fuel, the major contaminants of concern are TPH, BTEX and VOCs. Monitoring of the well north of the purge tanks (WS-22) by Tinker AFB has not shown detectable quantities of VOCs. However, this well is clearly up gradient and withdraws water from the regional aquifer, not the perched system.

2. Approach

The Fuel-Purge Area was designated as a key test area to demonstrate the ability of the LIF-CPT probe to characterize JP-4/JP-5 contaminated soil. As discussed previously, the field program for the Fuel-Purge Area was essentially doubled from that presented in the DT&E plan. As shown in Table 3, 55 LIF-CPT profiles, 15 soil sample locations yielding over 60 soil samples from both CPT probing and drilling, and 6 water samples retrieved from drill holes were accomplished. Total LIF-CPT footage for the test area was 927 feet, approximately 60 percent of the DT&E program total.

The DT&E field investigation addressed three of the four sub-sites described above. The main focus of the LIF-CPT demonstration was characterization of the fuel dump turnaround area. The purge USTs and the waste fuel aboveground tanks were allotted one day of LIF-CPT profiling with one soil and water sample location each. The fuel hydrant system was eliminated as a DT&E site in order to allow additional assessment of the fuel dump turnaround.

An objective of the field program at the turnaround area was to supply necessary site characterization information for remedial actions at the old ramp site. In addition to supplying the

necessary information, the LIF-CPT also identified and further delineated a previously unknown spill located west of the bunker.

Initially, a rectangular grid with push sites spaced 50-feet apart was laid out in the turnaround area. This grid was executed for 11 locations, FPA-01 through FPA-11. LIF readings were observed below 6 feet on FPA-03. This was expected as FPA-03 was located about 10 to 20 feet southwest of the old ramp location. On the eleventh push located 50 feet west of the old ramp (FPA-11), a second LIF hot zone was indicated that was significantly higher in amplitude than FPA-03, and extended from depths of 0.5 feet to 10 feet.

To verify the LIF results, a shovel sample was taken from 0.5 to 1.0 feet near the push site (sample FPA-G11). A very strong petroleum odor was indicated a few inches below the ground surface and the soil consistency and appearance was consistent with hydrocarbon contamination. A HNu photoionization detector was used to confirm the olfactory evidence; 90 ppm of benzene was obtained. Chemical analyses obtained on the sample indicated a TPH value of 4700 mg/kg.

Examination of surface conditions around FPA-11 indicated a filled area and distressed vegetation (see Figure 26). Additional probing with a shovel indicated that the filled area was comprised of a thin cover of clean sandy clay soil over possible petroleum-contaminated soils. The available evidence suggested that the contamination at FPA-11 was not due to the old ramp source, but possibly resulted from a separate spill.

With support from the Tinker AFB project coordinator, this hypothesis was tested using a more detailed site characterization strategy. LIF-CPT profiling was used to examine the lateral and vertical extent of soil contamination, with push locations determined by the real-time LIF results. Using onsite scientific visualization, the increased horizontal resolution would allow a truly three-dimensional assessment of the problem area. This strategy was consistent with the AFSCAPS objective of using three-dimensional graphics of cone penetrometer data to guide and direct the site characterization study.

Following the change in strategy, two days were used to complete 25 pushes in the distressed area near the turnaround; the push rate was increased to a "normal" CPT rate of 1.5 cm/sec during

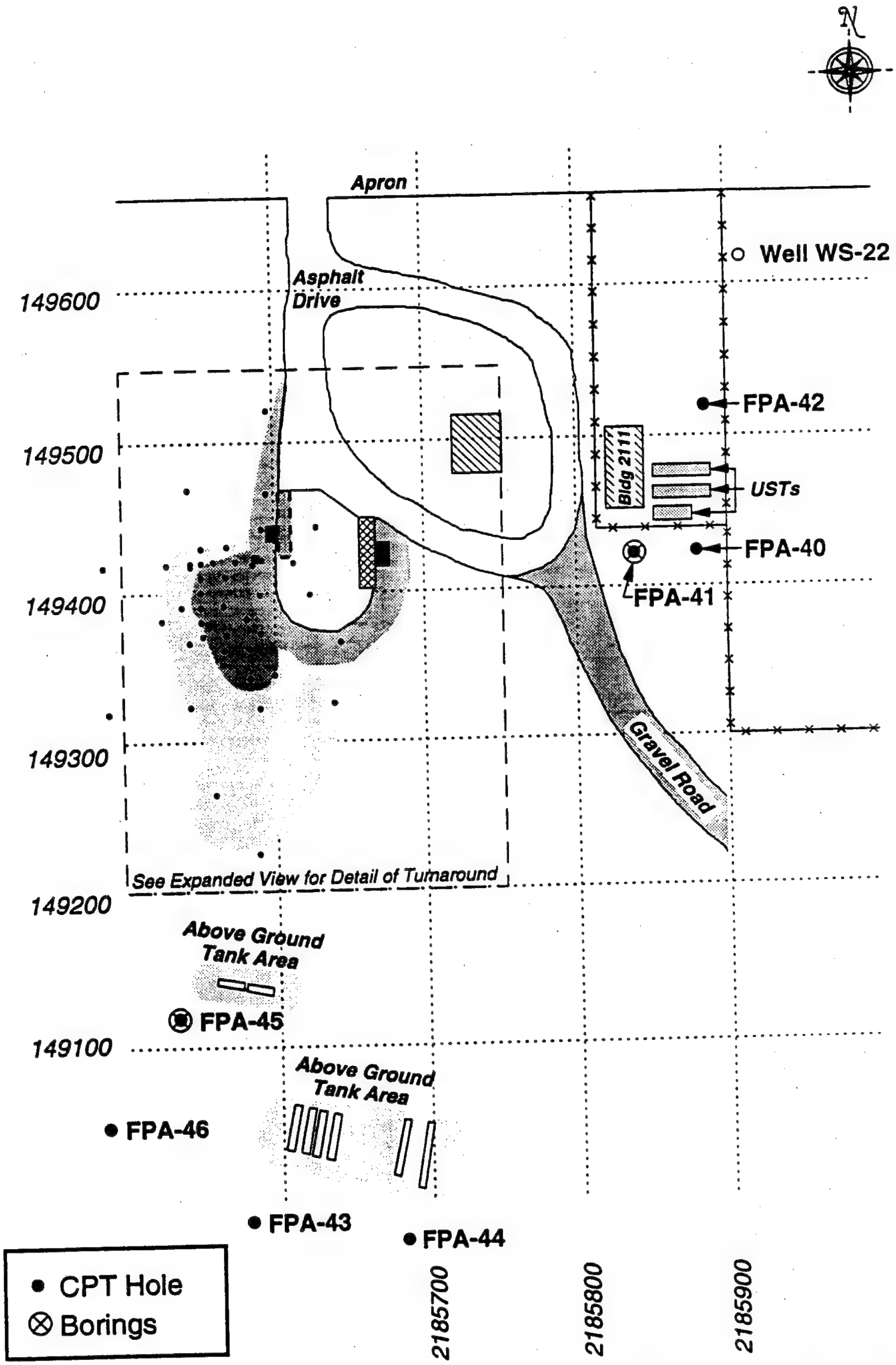


Figure 26. Site Map of the Fuel-Purge Area Showing USTs, Above Ground Tanks, and the Turnaround Area.

this time. A minimum grid spacing of 10 feet for push sites was used within the disturbed area. When the LIF-CPT indicated only background readings, the spacing was increased to 20 feet. An additional two days of CPT time was taken to perform LIF-CPT pushes in the vicinity of the purge USTS and waste fuel tanks, "fill-in" pushes near the turnaround, and a repeatability study near FPA-03.

The soil sampling and analysis plan was used to corroborate the LIF results in the area. Using the standard 5-foot interval for sampling, 12 sample locations (four drill and eight CPT) were performed near the turnaround site. Three additional locations were sampled at the other two sub-sites. All drill holes were sampled for water and used for determination of quasi-stabilized water levels.

3. Results

The 55 CPT profiles performed across the Fuel-Purge Area have an average depth of 17 feet. As shown in Figure 27, a typical soil profile for the Fuel-Purge Area consists of a 2- to 3-foot thick sand layer followed by a sand mixture consisting of either silty sands or sandy clays with interbedded silty clays. A dense fine sand material generally precedes the CPT refusal.

The CPT refusal surface has been mapped in Figure 28. Similar to the North Tank Area, the drill samples confirm that the CPT refusal surface is the top of a sandstone layer. Below the sandstone a heavily weathered shale sequence is present. The sandstone layer appears to parallel the ground surface in that it dips to the south at a 1 to 5 percent gradient.

Water levels measured in the open drill holes allow estimates of the water table surface configuration. The water levels were measured September 24, 1992, 1 to 2 days after drilling, and were not completely stabilized. Using a 100-foot grid, a generalized groundwater contour map is provided in Figure 29. A southwesterly groundwater flow direction is suggested from the map.

A strategy of using a tighter grid-spacing with LIF-CPT profiling based on the LIF results served to delineate several "hot" zones from one another. This fact is best demonstrated by visualization of the data with a series of slices and isosurfaces of the "hot" zones. Sampling and

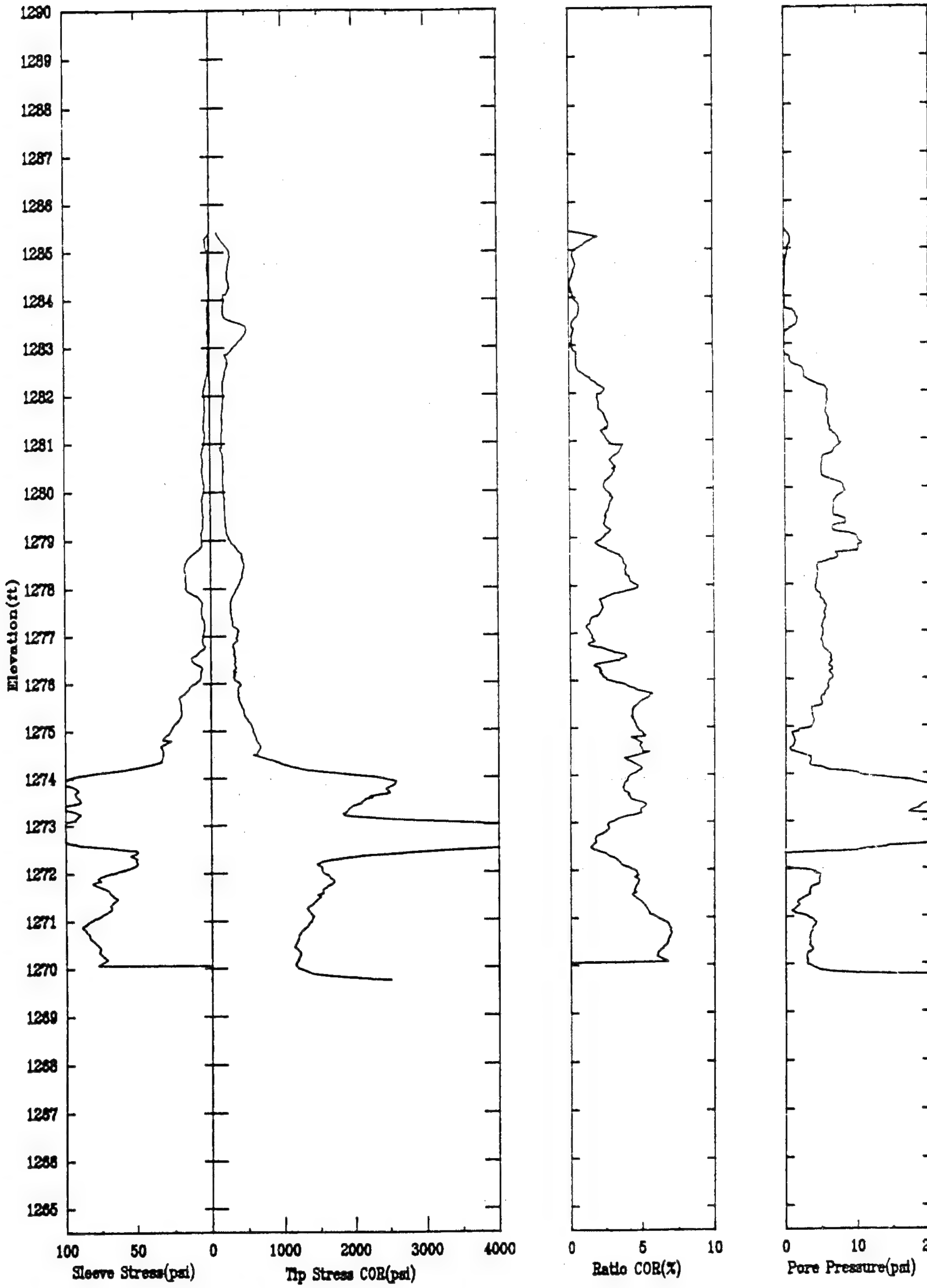


Figure 27. A Typical LIF-CPT Profile from the Fuel-Purge Area.

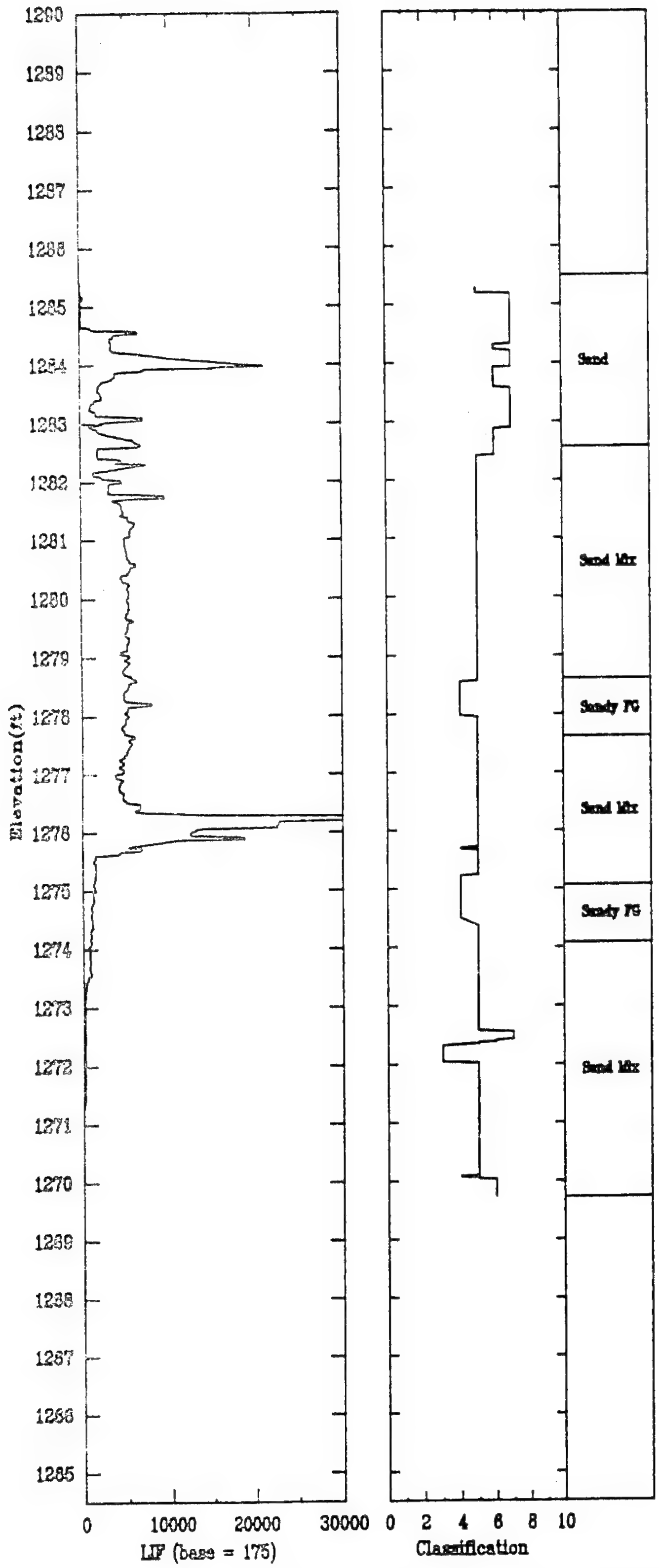


Figure 27. A Typical LIF-CPT Profile from the Fuel-Purge Area (Concluded).

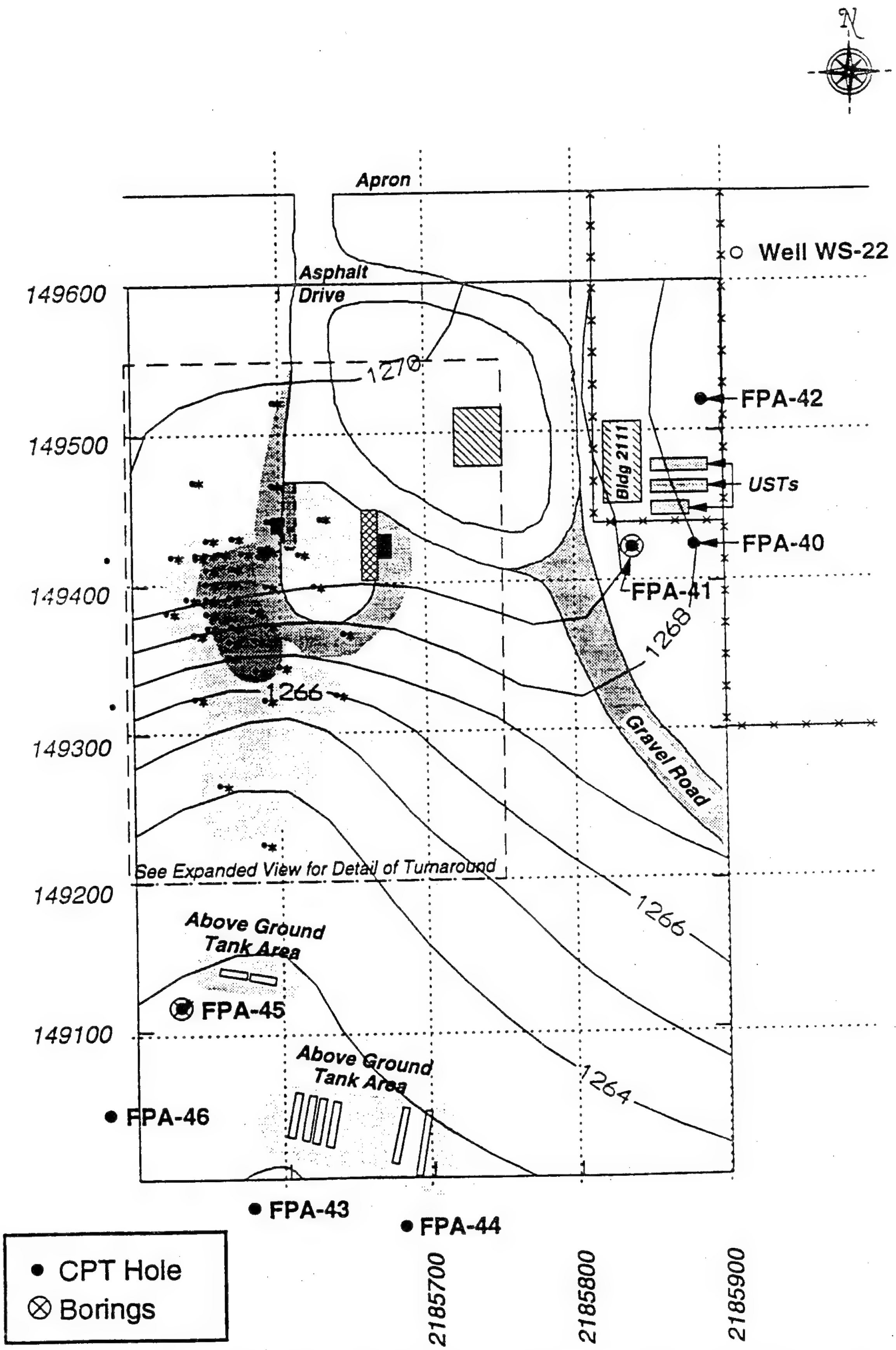


Figure 28. Contours of the CPT Refusal Surface (ie. Top of the Sandstone Layer) at the Fuel-Purge Area.

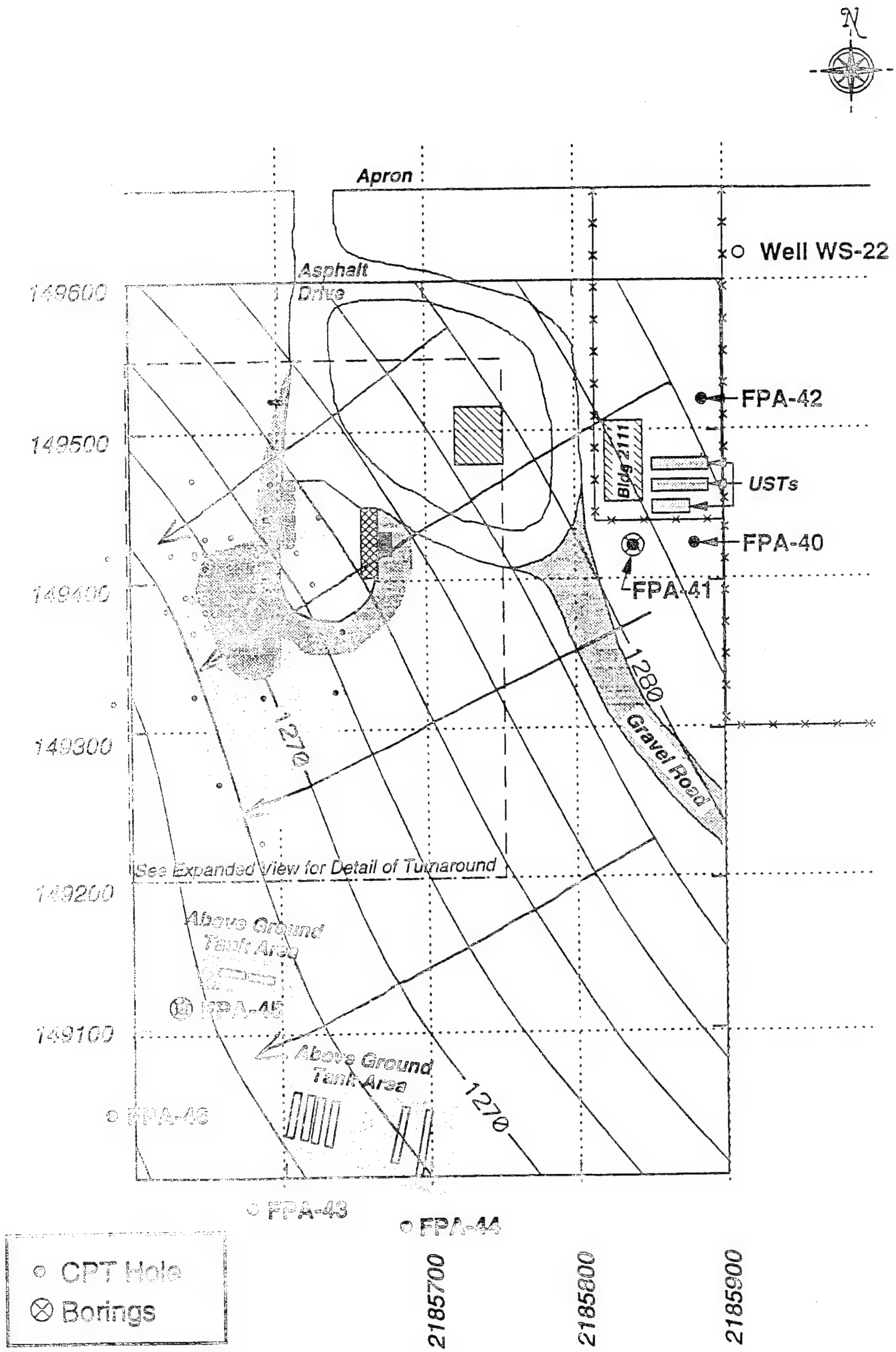


Figure 29. Groundwater Elevation Contours for the Fuel-Purge Area.

analysis data corroborate that the values of high LIF correspond to locations of petroleum-contaminated soils.

Figures 30 and 31 show isosurfaces with LIF values of 500 counts or greater and 1000 counts or greater respectively for the Fuel Turnaround Area. Both isosurfaces clearly show two contaminated zones. As presented in Volume I, LIF values of 500 and 1000 are normally indicative of a TPH values of approximately 1,000 mg/kg. Figures 32 and 33 are horizontal slices of the LIF distribution for the same area. These two figures clearly indicate both that the two plumes are separate and also that the western plume is shallower and more intense than the eastern plume. Both figure types were generated using ARA's three-dimensional site visualization software. A statistical grid with 5-foot horizontal and 1-foot vertical separation was used in the pre-processing. The statistical modeling tends to smooth the actual results. To assist in further visualization the model zone was reduced to concentrate solely on the two spills in the turnaround area.

Two main bodies of residual soil contamination located in the turnaround area are represented in more detail by the horizontal slices in Figures 34 through 36. The visualization indicates that these main contamination zones are less than 40 feet wide. A separation of about 15 feet exists between the newly-discovered spill (western body) and the old ramp spillage (eastern body), suggesting independent origins. A smaller body is located 40 feet south of the western body, and is centered near station FPA-20.

Four isosurfaces presented in Figures 37 through 40 help to present the vertical of the contamination and also the possible sources. The geometry of the western contaminant body is indicative of a surface spill. High LIF values extend from near the surface to a depth of over 14 feet. Additionally, LIF values and chemical analyses of the shallow soils in the distressed area suggest a spill contaminant source as well. The extent of the contamination is extensive for LIF values above 250 and 400. For LIF values above 1000, three contamination zones are clearly evident, with the southern plume being the least contaminated. The most contaminated zone is the western zone as shown with LIF values above 5000.

The vertical extent of this body as indicated by the LIF data corresponds to an elevation of 1273 feet, or a depth of about 12 feet. This depth is significant for several reasons. The CPT

Fuel Purge Area
LIF > 500

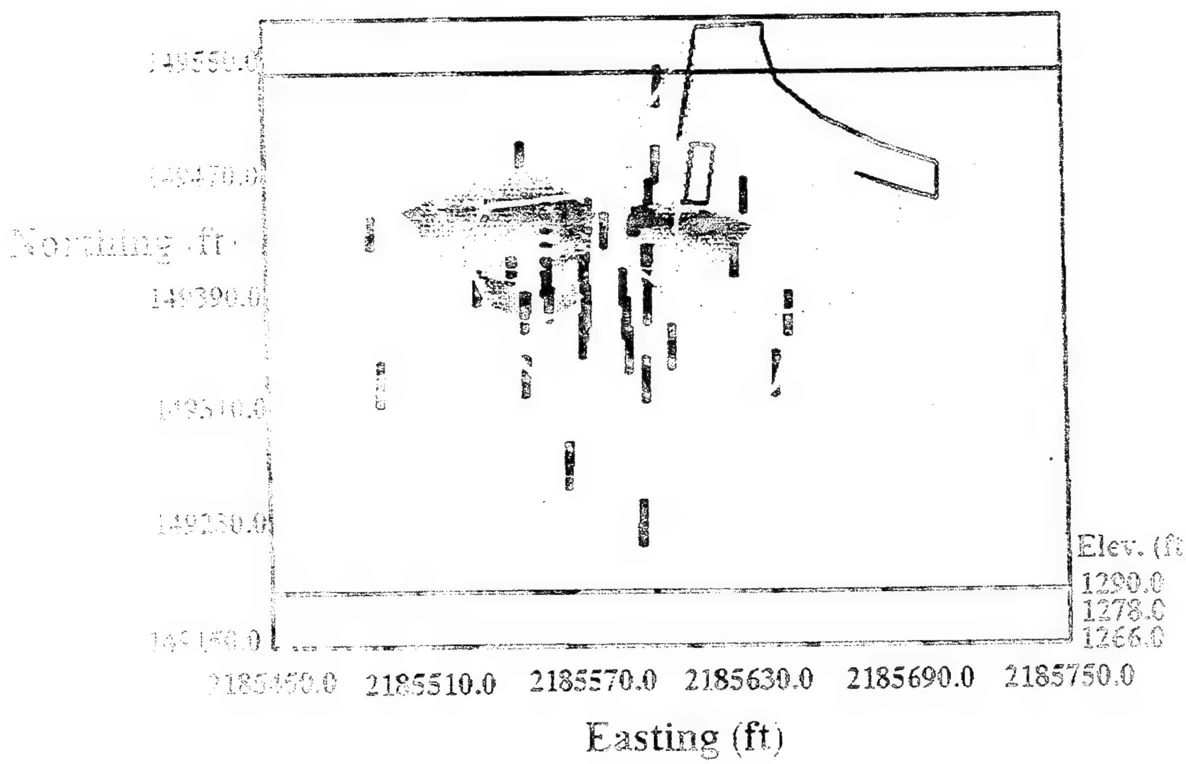


Figure 30. Isosurface of the Entire Fuel Turnaround Area Showing Soil Volumes with LIF Values Above 500.

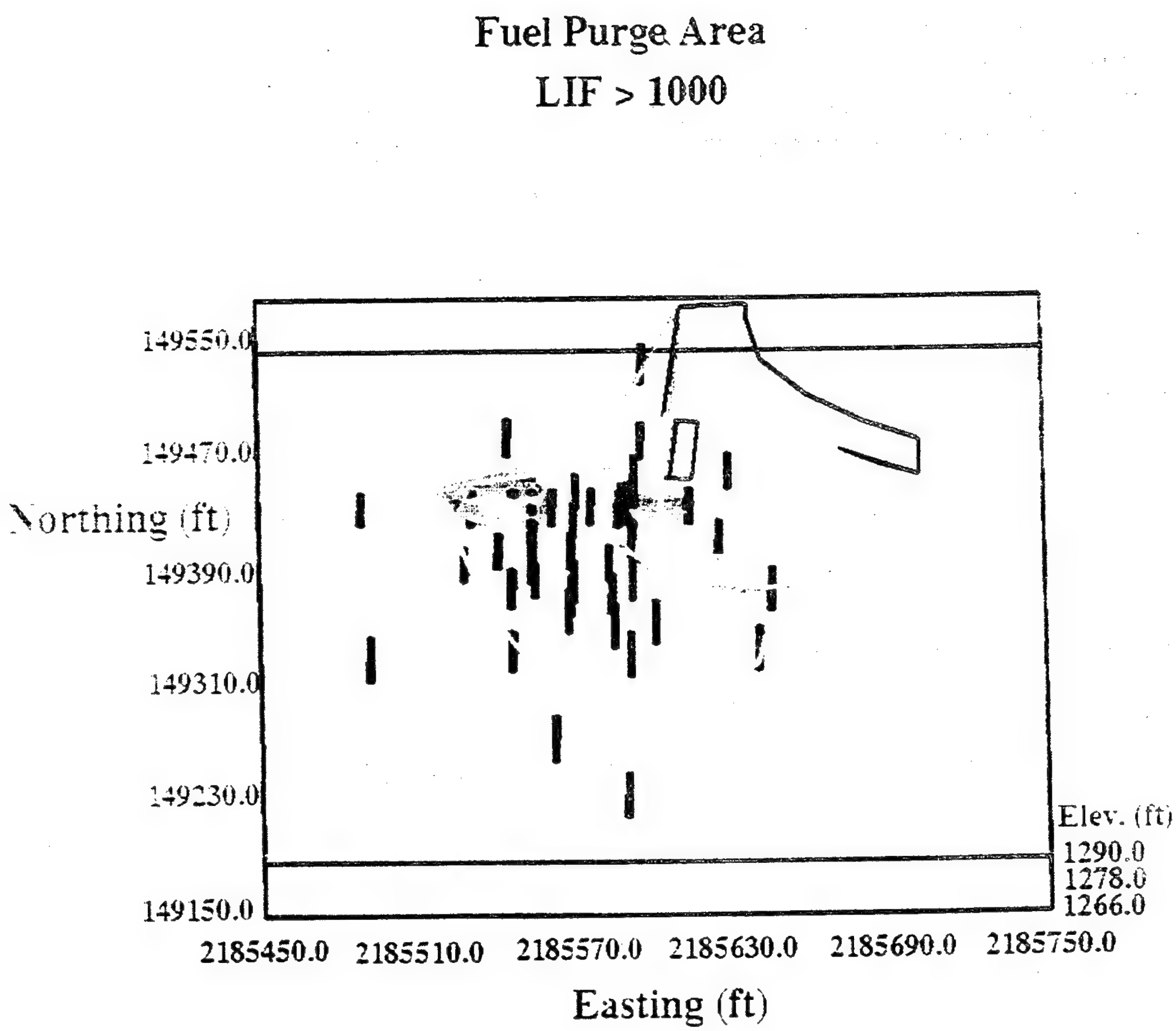


Figure 31. Isosurface of the Entire Fuel Turnaround Area Showing Soil Volumes with LIF Values Above 1000.

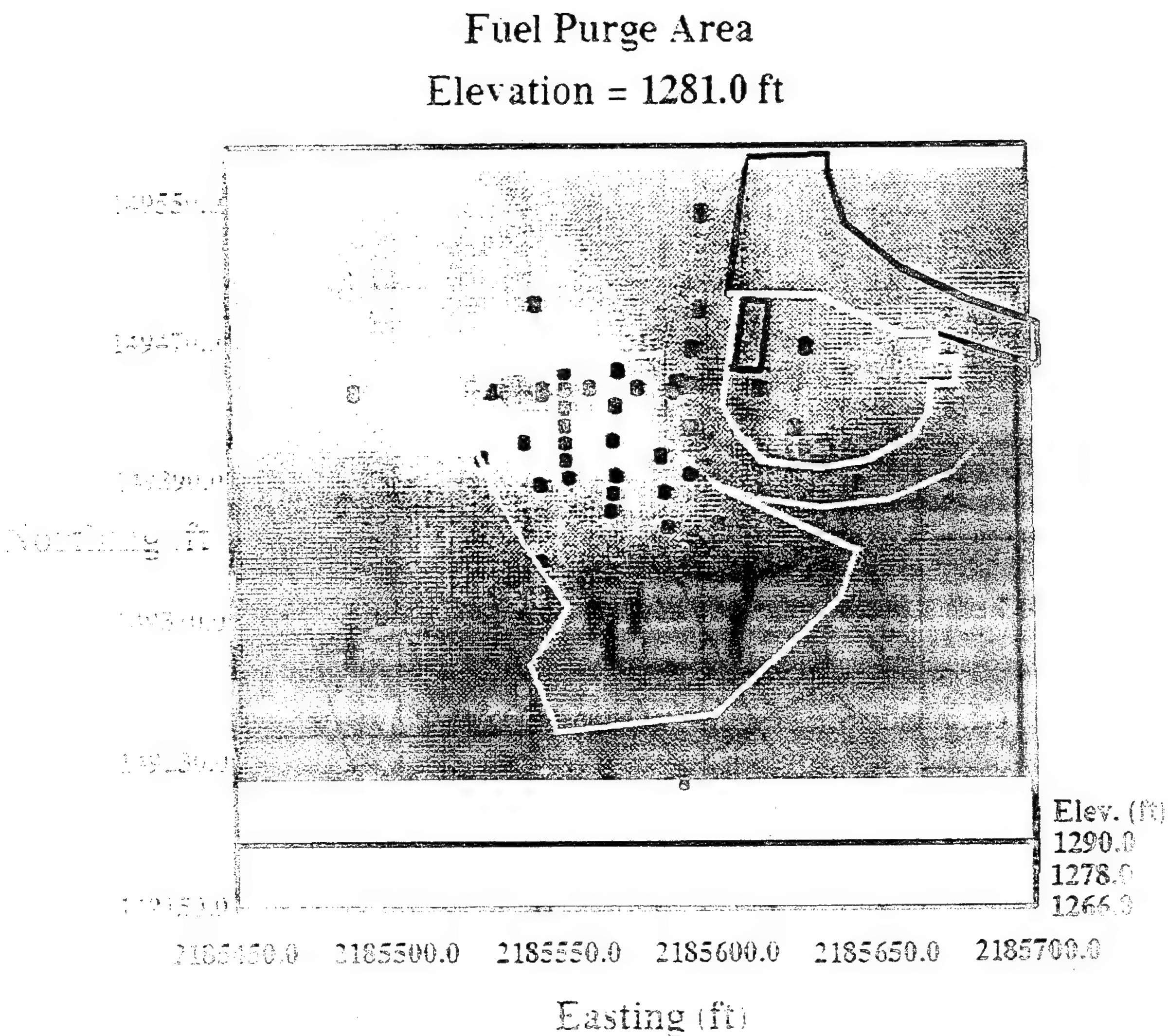


Figure 32. Horizontal Slice of the Entire Fuel Turnaround Area at an Elevation of 1281.0 Feet.

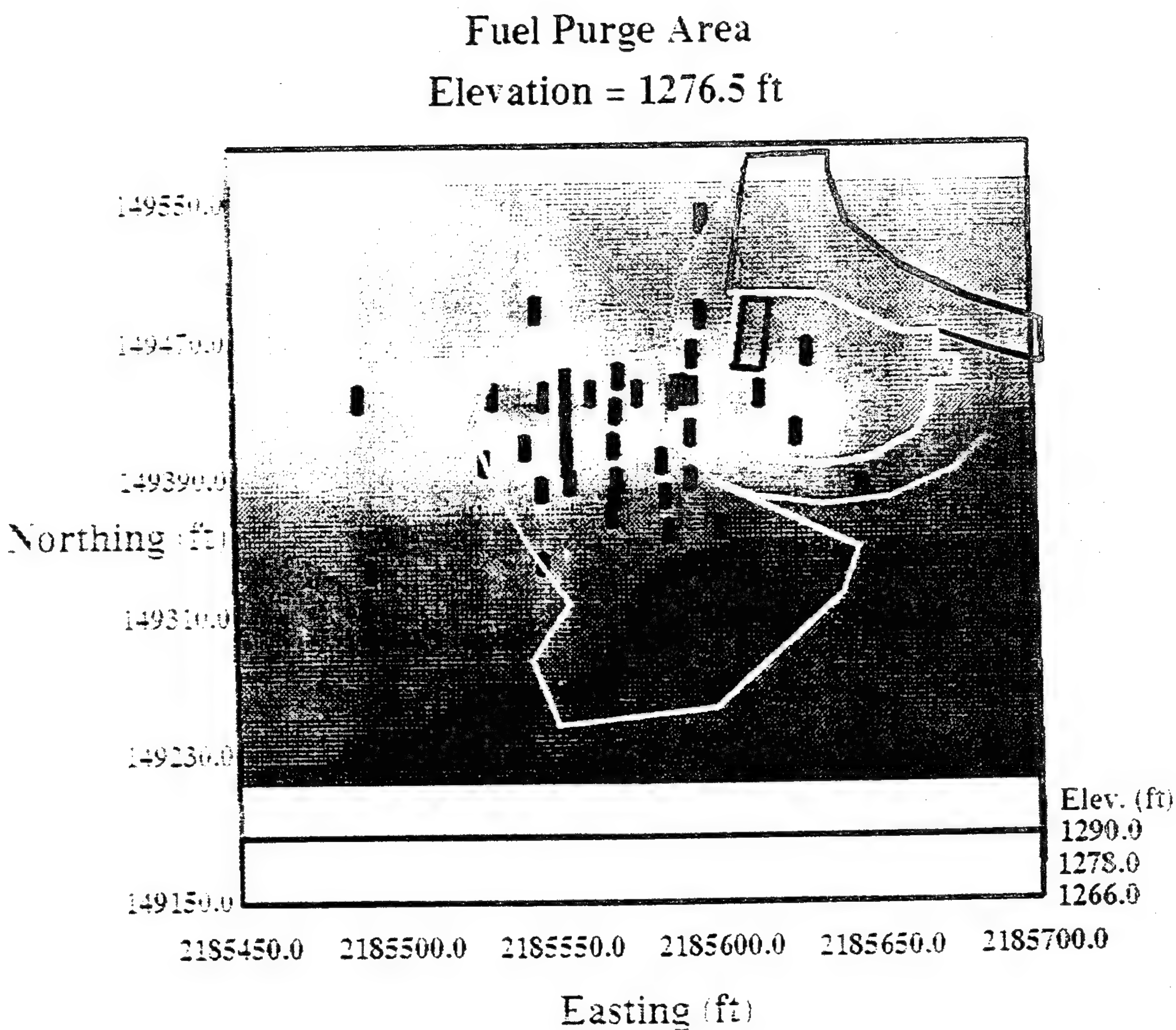


Figure 33. Horizontal Slice of the Entire Fuel Turnaround Area at an Elevation of 1276.5 Feet.

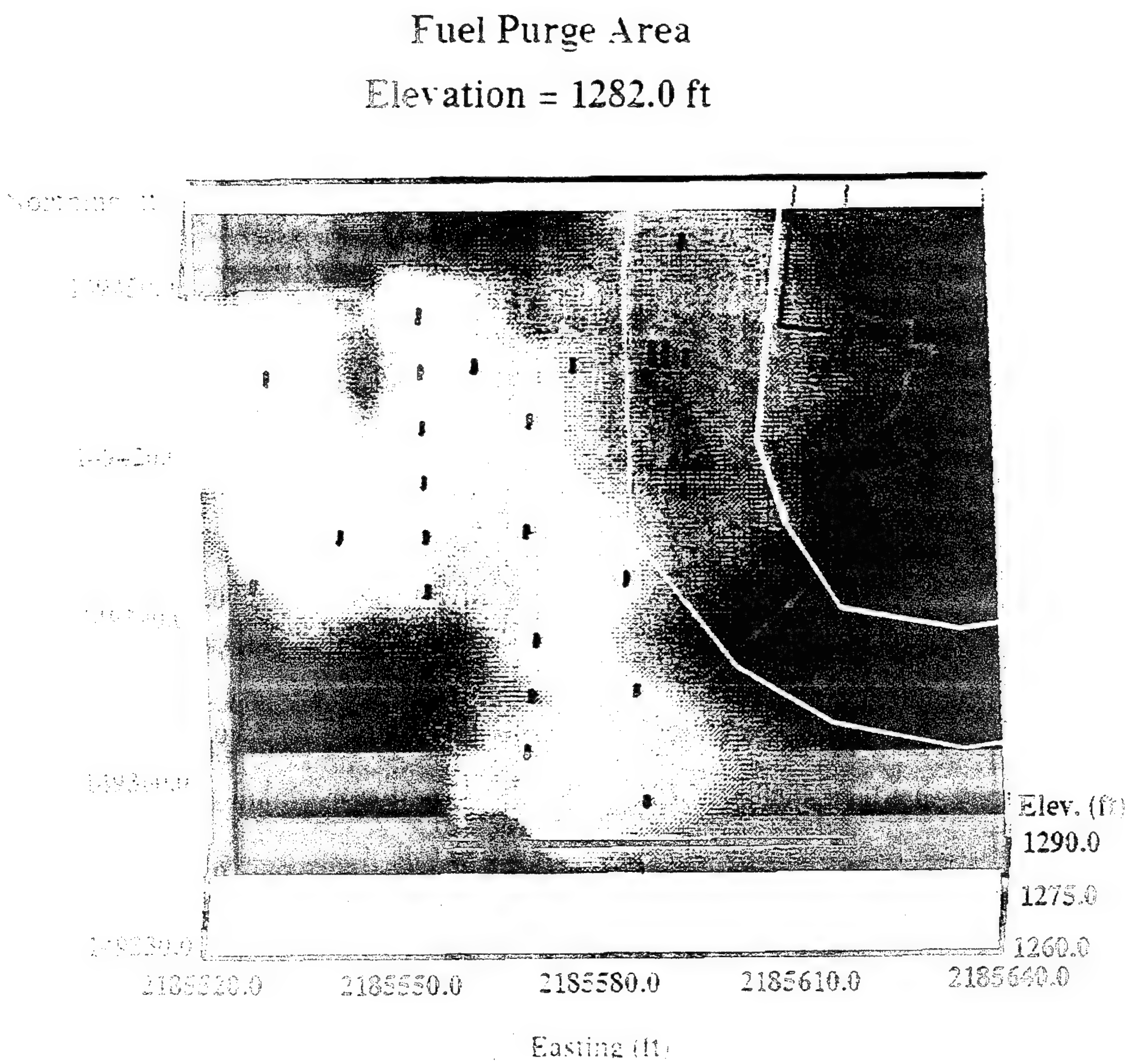


Figure 34. Horizontal Slice of the Fuel Turnaround Area at an Elevation of 1282.0 Feet.

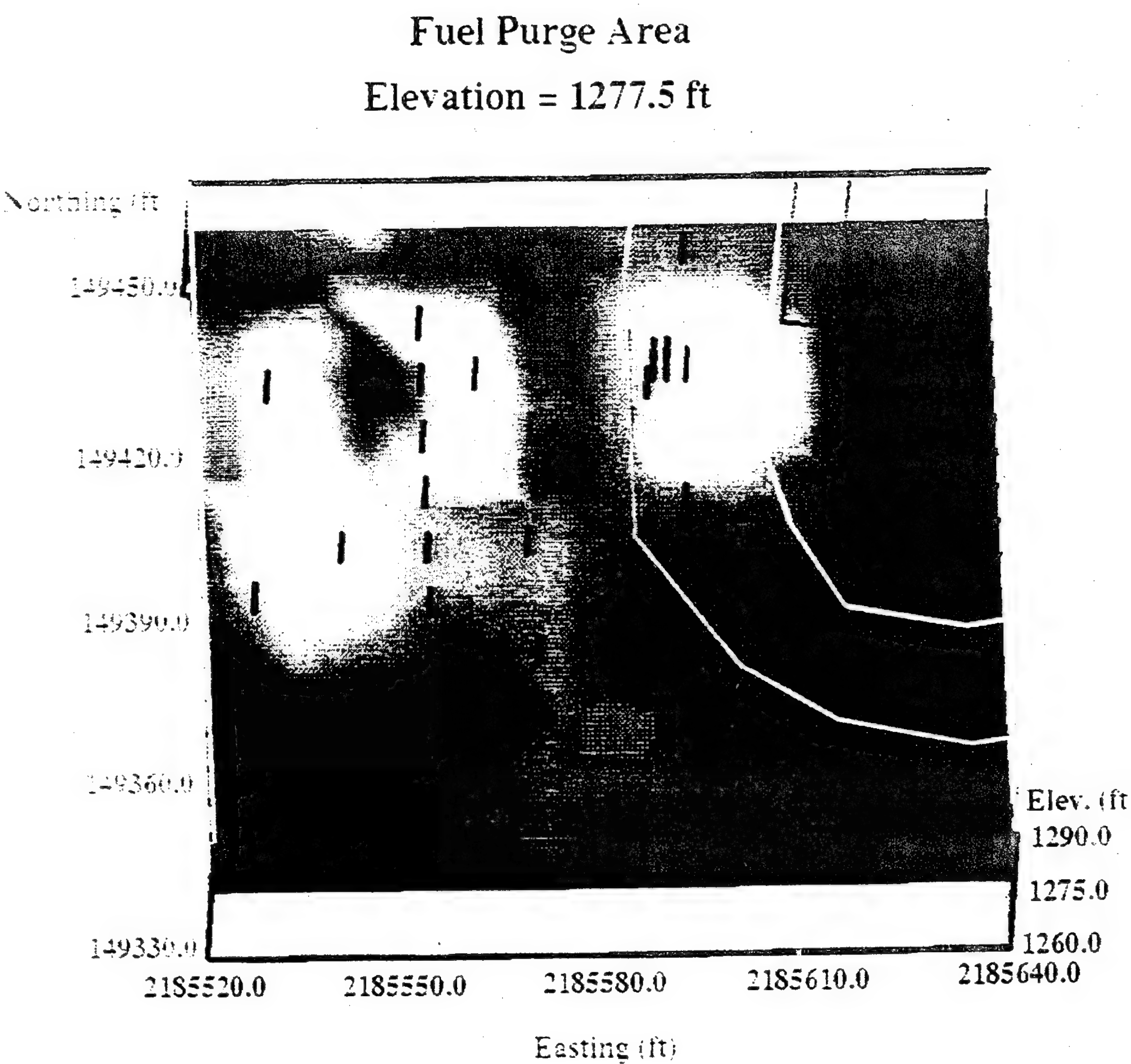


Figure 35. Horizontal Slice of the Entire Fuel Purge Area at an Elevation of 1277.5 Feet.

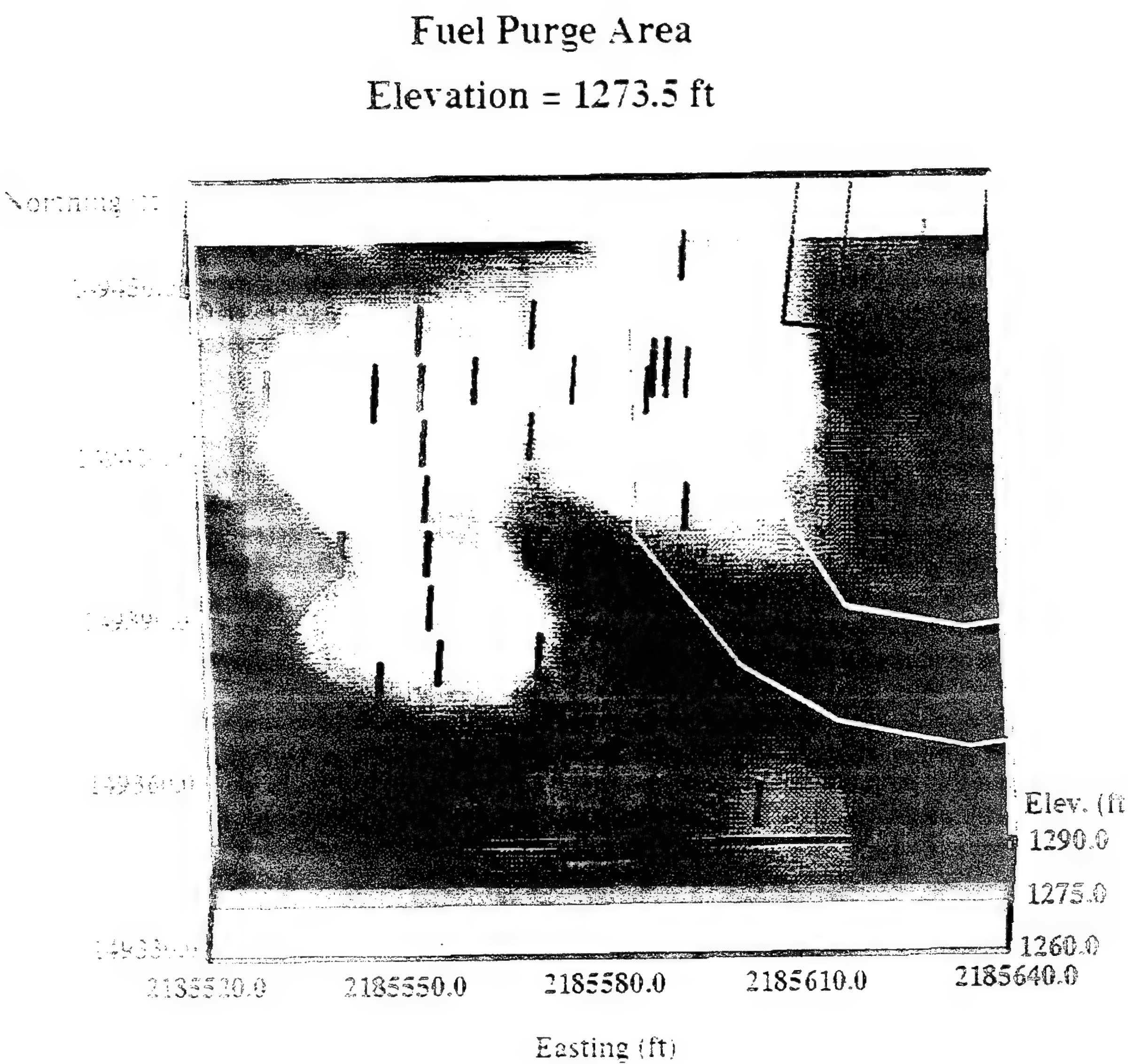


Figure 36. Horizontal Slice of the Entire Fuel Purge Area at an Elevation of 1273.5 Feet.

Fuel Purge Area

LIF > 250

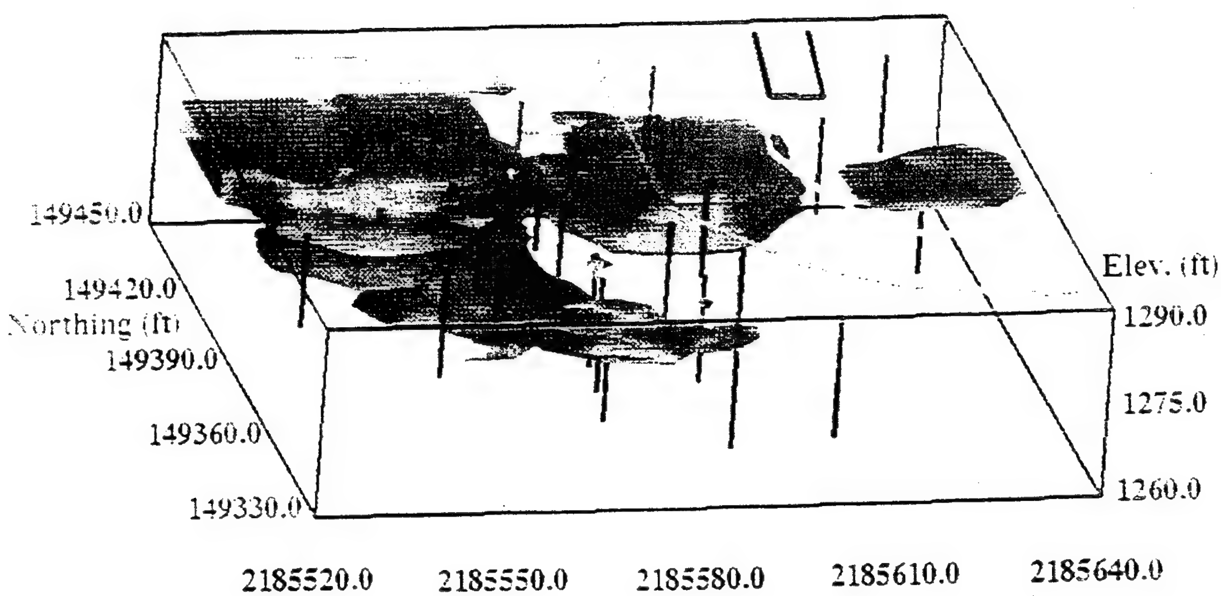


Figure 37. Isosurface of LIF Values Greater than 250 in the Fuel Purge Turnaround Area Showing a Large Extent of Contamination.

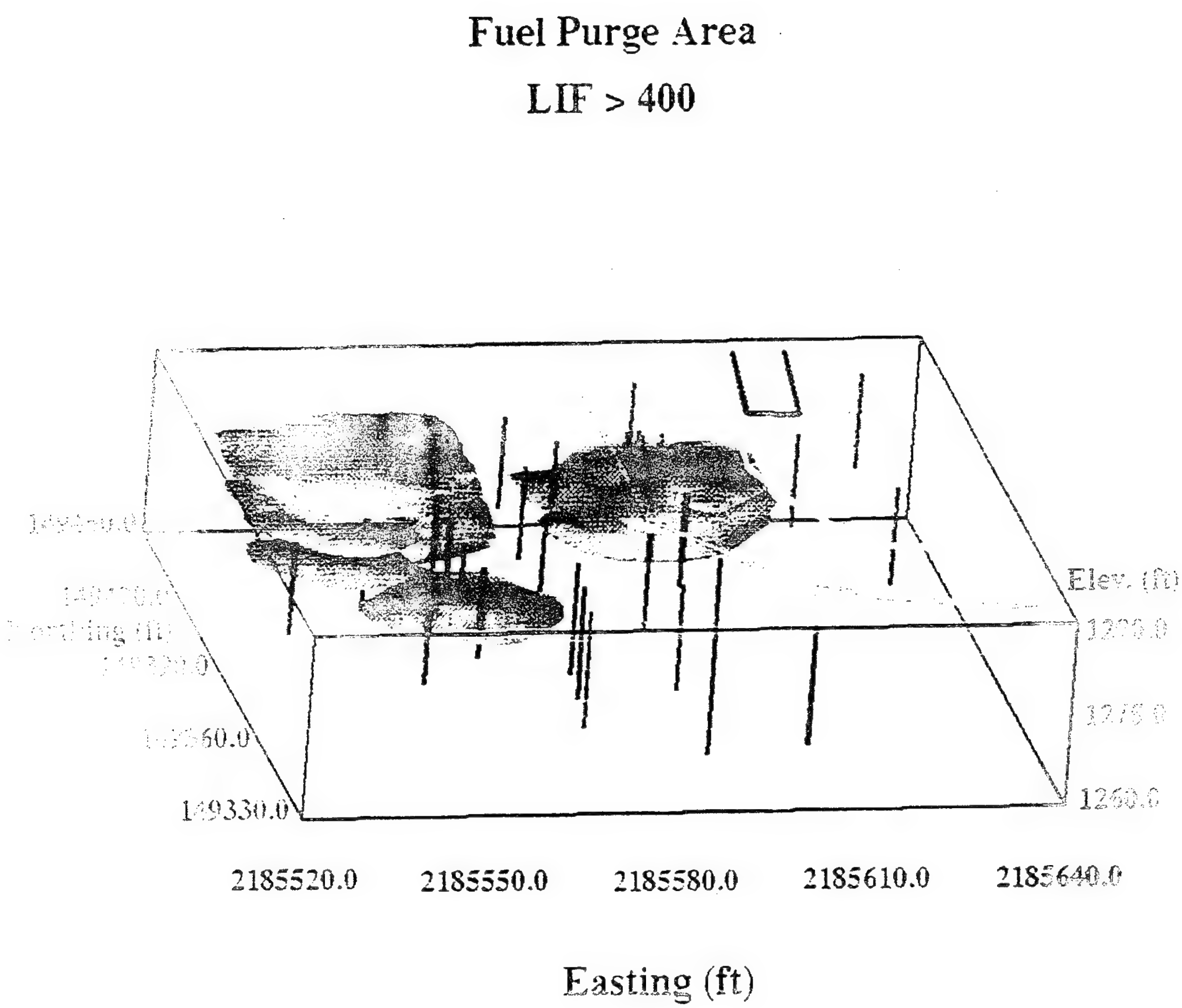


Figure 38. Isosurface of LIF Values Greater than 400 in the Fuel Purge Turnaround Area Showing 3 Zones and Some Variances with Depth.

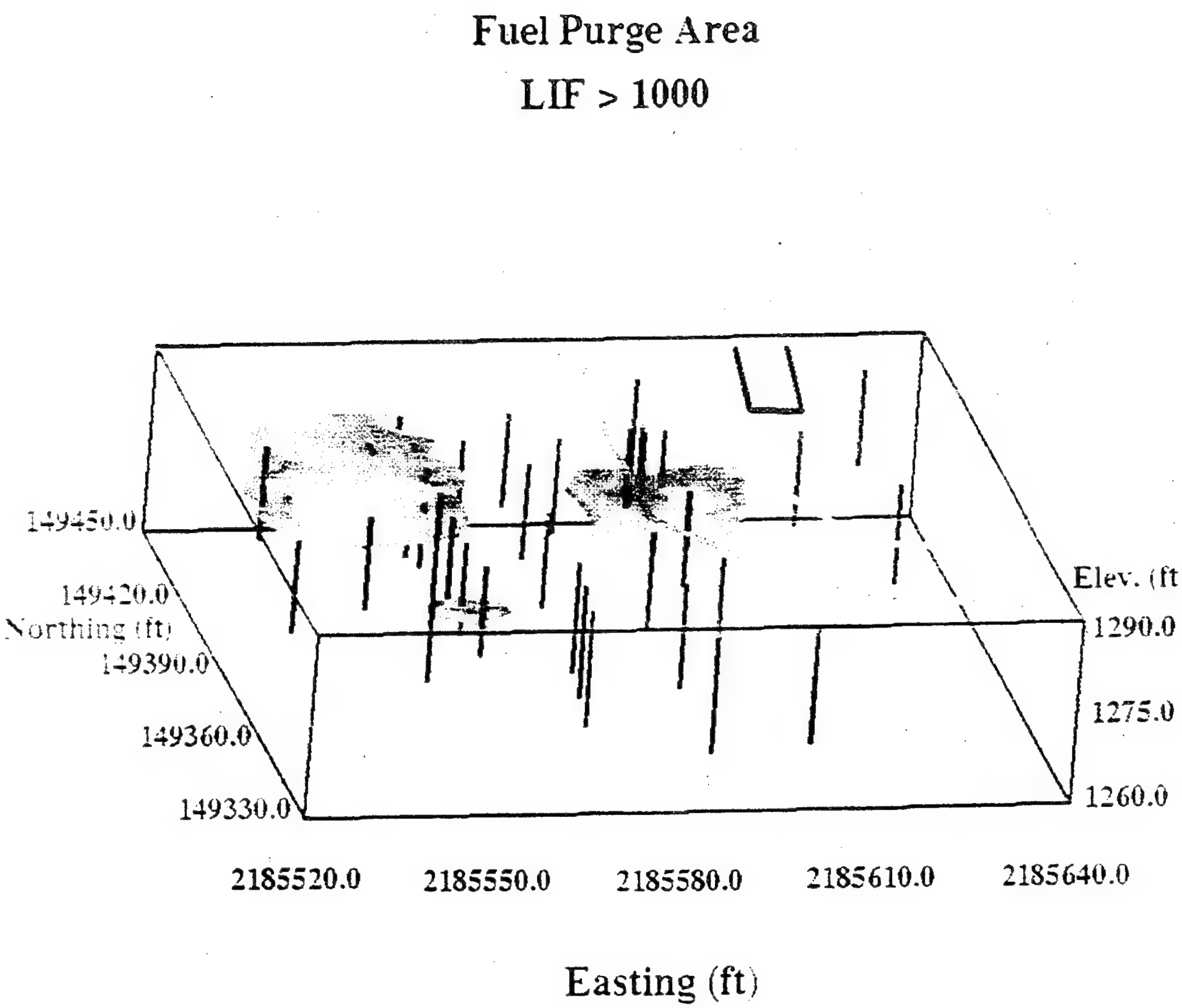


Figure 39. Isosurface of LIF Values Above 1000 in the Fuel Purge Turnaround Area Showing 3 Separate Plumes.

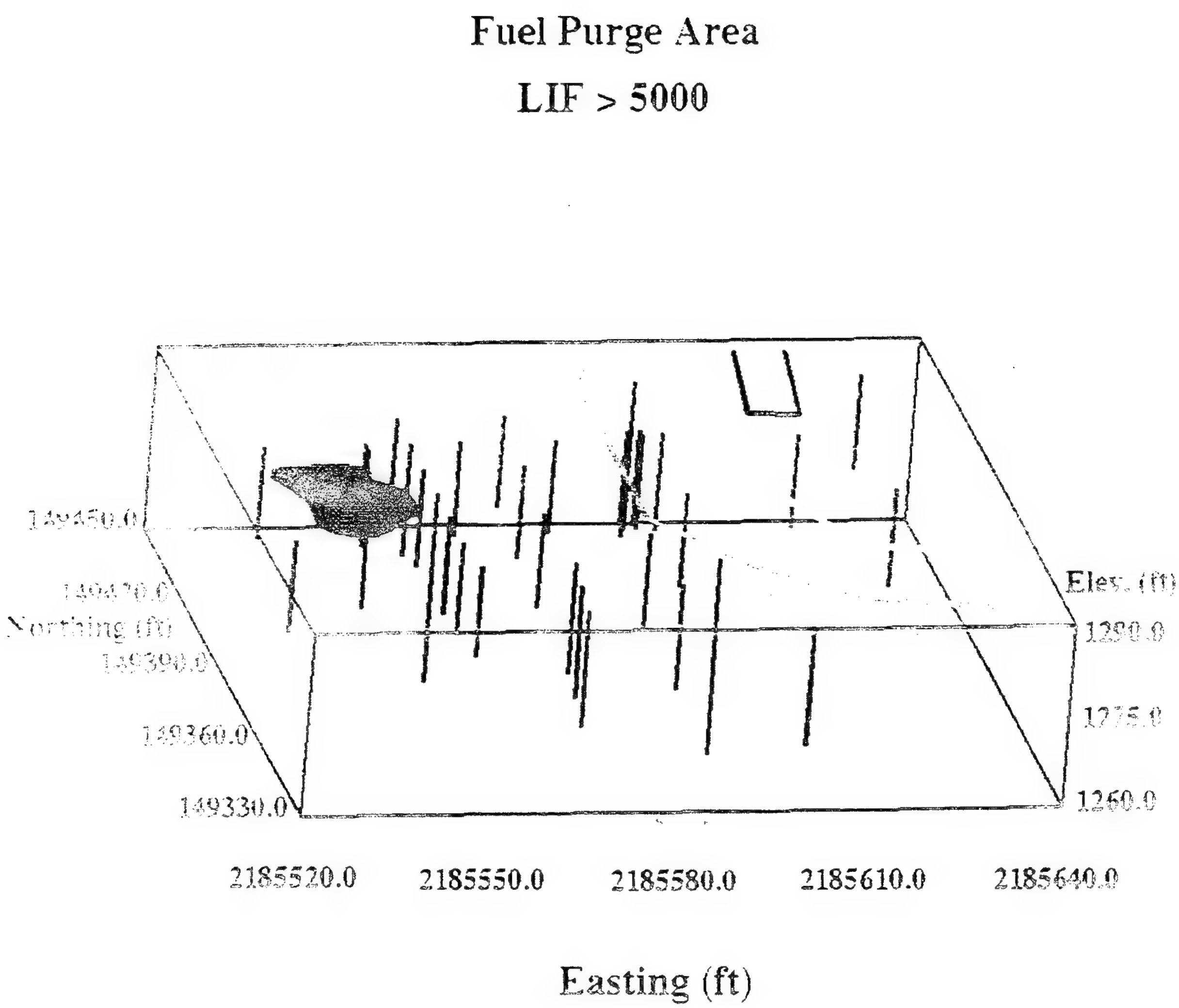


Figure 40. Isosurface of LIF Values Above 5000 in the Fuel Purge Turnaround Area Showing Only the Region of High Contamination.

refusal layer, designated as the upper surface of the sandstone, is at elevation 1270 feet, whereas the perched water table is also located at an elevation of 1270 feet. Thus, the majority of residual product appears to remain in the unsaturated zone. The perched water table surface or low permeability conditions of the sandstone layer may serve to restrict the fuel movement.

Visualization of the eastern body near the old ramp is not indicative of a surface spill, but this is probably a result of the following: (1) a larger grid spacing used in this area, (2) limitations posed by the concrete pad, i.e., fixed pavement core locations, and most probably, (3) removal of the most grossly-contaminated soils during dismantling of the old ramp.

Soil chemical results for the fuel dump turnaround are presented in Tables 9 through 12. C PT sampling locations used in the table were FPA-03, 04, 05, 11, 12, 13, 20, and 47 and the dri ll holes used were FPA-B01, B31, B32, and B33. The most notable item is that all 47 samples tested for TPH had detectable amounts, although 19 had TPH values of less than 50 mg/kg. About half of the samples tested had detectable quantities of BTEX or naphthalene. Some chlorinated solvents tested positive, suggesting a contaminated or waste fuel was spilled.

TPH and BTEX values from drill holes FPA-B31, B32 and B33 show a rapid decline in values below the CPT refusal layer. However, a slightly greater depth of contamination is indicated at FPA-B33, which is near the old ramp. The accumulation of spilled fuel over a number of years may account for the apparently deeper infiltration of fuel at this location. Of all the water samples, FPA-B33 also had the greatest amount of BTEX.

LIF-CPT profiles made downgradient of the purge USTs (FPA-40 and FPA-41) had high LIF zones which were corroborated by follow-up sampling and analyses. The vertical extent of petroleum contamination at FPA-41 was tightly constrained by the LIF and BTEX measurements. Drillhole FPA-B41 had some groundwater contamination in the grab sample taken on September 24, 1992. Soil samples from LIF-CPT station FPA-42, the up gradient station near WS-22, showed nondetectable quantities of BTEX and naphthalene, as suggested by the LIF results.

TABLE 9. ONSITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA.

Soil Samples

Location		FPA-47	FPA-47	FPA-B01	FPA-B01	FPA-B01	FPA-B01	FPA-B31	FPA-B31	FPA-B31
Depth Interval From	ft	10.00	15.00	0.75	4.75	9.75	14.75	2.5	0.75	5.75
To	ft	10.60	15.60	1.25	5.25	10.75	15.25	3.5	1.25	6.25
Benzene	(mg/kg)	<0.020	<0.020	0.056	<0.020	<0.020	<0.020	0.708	<0.020	<0.020
Toluene	(mg/kg)	<0.020	<0.020	0.226	<0.020	<0.020	<0.020	2.564	<0.020	0.010
Ethyl Benzene	(mg/kg)	<0.020	<0.020	0.193	<0.020	<0.020	<0.020	<0.020	0.020	0.025
M-Xylene	(mg/kg)	<0.020	<0.020	0.556	<0.020	<0.020	<0.020	20.550	0.034	0.087
Naphthalene	(mg/kg)	<0.020	<0.020	2.901	0.041	<0.020	<0.020	1.130	3.629	0.590
2 methyl Naphthalene	(mg/kg)	<0.020	<0.020	0.726	0.072	<0.020	<0.020	0.232	1.056	0.620

Soil Samples

Location		FPA-B31	FPA-B31	FPA-B31	FPA-B31	FPA-B31	FPA-B32	FPA-B32	FPA-B32	FPA-B32
Depth Interval From	ft	8	10.75	12.75	15.75	18.75	0.75	5.75	9.75	13.75
To	ft	9	11.25	13.25	16.25	19.25	1.25	6.25	10.25	14.25
Benzene	(mg/kg)	0.592	<0.020	<0.020	<0.020	<0.020	<0.020	0.158	<0.020	<0.020
Toluene	(mg/kg)	2.595	<0.020	<0.020	<0.020	<0.020	0.117	1.030	<0.020	0.063
Ethyl Benzene	(mg/kg)	3.614	<0.020	<0.020	<0.020	<0.020	0.094	0.563	<0.020	0.059
M-Xylene	(mg/kg)	21.989	0.055	<0.020	<0.020	<0.020	0.122	0.809	<0.020	0.129
Naphthalene	(mg/kg)	1.102	0.930	0.122	<0.020	<0.020	1.099	3.302	0.018	0.400
2 methyl Naphthalene	(mg/kg)	0.347	0.953	0.154	0.031	<0.020	1.007	0.856	0.119	0.444

TABLE 9. ONSITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA (CONCLUDED).

Soil Samples

Location		FPA-03	FPA-03	FPA-03	FPA-04	FPA-04	FPA-04	FPA-05	FPA-05	FPA-05
Depth Interval From	ft	5.00	10.00	15.00	5.00	10.00	15.00	5.00	10.00	15.00
To	ft	5.60	10.60	15.60	5.60	10.60	15.60	5.60	10.60	15.60
Benzene	(mg/kg)	0.191	<0.020	<0.020	0.172	0.098	<0.020	<0.020	<0.020	<0.020
Toluene	(mg/kg)	0.368	1.271	<0.020	0.373	0.231	<0.020	<0.020	<0.020	<0.020
Ethyl Benzene	(mg/kg)	0.156	1.250	<0.020	0.294	0.516	<0.020	<0.020	<0.020	<0.020
M-Xylene	(mg/kg)	0.595	1.239	<0.020	0.519	0.680	<0.020	<0.020	<0.020	<0.020
Naphthalene	(mg/kg)	3.132	4.123	0.037	1.099	5.287	<0.020	<0.020	<0.020	<0.020
2 methyl Naphthalene	(mg/kg)	0.954	0.209	0.041	1.081	0.455	<0.020	<0.020	<0.020	<0.020

Soil Samples

Location		FPA-11	FPA-11	FPA-11	FPA-11	FPA-11	FPA-12	FPA-12	FPA-12	FPA-13
Depth Interval From	ft	0.50	1.25	5.00	9.00	15.00	5.00	10.00	15.00	5.00
To	ft	1.00	1.75	5.60	9.60	15.60	5.60	10.60	15.60	5.60
Benzene	(mg/kg)	<0.020	<0.020	0.020	<0.020	<0.020	<0.020	0.055	<0.020	<0.020
Toluene	(mg/kg)	0.137	8.324	0.092	0.085	<0.020	2.790	0.274	0.022	0.016
Ethyl Benzene	(mg/kg)	0.094	0.899	0.060	0.175	<0.020	0.669	0.172	<0.020	<0.020
M-Xylene	(mg/kg)	0.565	33.378	0.586	0.768	<0.020	4.618	0.362	0.024	0.019
Naphthalene	(mg/kg)	4.285	1.461	4.368	3.386	0.136	3.499	2.429	<0.020	0.043
2 methyl Naphthalene	(mg/kg)	0.209	0.462	0.616	0.597	0.157	0.987	1.766	<0.020	0.076

Soil Samples

Location		FPA-13	FPA-13	FPA-20	FPA-20	FPA-20	FPA-42	FPA-42	FPA-42	FPA-47
Depth Interval From	ft	10.00	15.00	5.00	10.00	15.00	5.00	10.00	15.00	5.00
To	ft	10.60	15.60	5.60	10.60	15.60	5.60	10.60	15.60	5.60
Benzene	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Toluene	(mg/kg)	0.015	0.016	0.049	0.030	<0.020	<0.020	<0.020	<0.020	<0.020
Ethyl Benzene	(mg/kg)	<0.020	<0.020	0.104	0.054	<0.020	<0.020	<0.020	<0.020	<0.020
M-Xylene	(mg/kg)	0.057	0.025	0.548	0.360	<0.020	<0.020	<0.020	<0.020	<0.020
Naphthalene	(mg/kg)	2.280	0.060	3.481	3.048	0.005	<0.020	<0.020	<0.020	<0.020
2 methyl Naphthalene	(mg/kg)	1.578	0.041	0.457	1.209	0.055	<0.020	<0.020	<0.020	<0.020

TABLE 10. ONSITE ANALYSIS OF WATER SAMPLES FROM FUEL PURGE AREA.

Water Samples

Location		FPA-B01	FPA-B31	FPA-B32	FPA-B33	FPA-B41	FPA-B45
Depth below ground surface, ft		wt	wt	wt	wt	wt	wt
Benzene	(ppb)	<20	<20	<20	88	<20	<20
Toluene	(ppb)	<20	<20	<20	44	<20	<20
Ethyl Benzene	(ppb)	<20	22	<20	324	38	<20
M-Xylene	(ppb)	<20	11	31	427	83	<20
Naphthalene	(ppb)	<20	173	143	313	523	68
2 methyl Naphthalene	(ppb)	<20	<20	56	174	31	41

TABLE 11. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA.

Soil Samples

Location		FPA-B01	FPA-03	FPA-03	FPA-03	FPA-04	FPA-04	FPA-04	FPA-05	FPA-05
Depth Interval From	ft	0.75	5	10	15	5	10	15	5	10
To	ft	1.25	5.6	10.6	15.6	5.6	10.6	15.6	5.6	10.6
Date Sampled		9/23/92	9/11/92	9/11/92	9/11/92	9/22/92	9/22/92	9/22/92	9/22/92	9/22/92
Total Petroleum Hydrocarbon	mg/kg	5600	780	5300	28	100	130	22	22	29
Benzene	mg/kg	<0.005	N/A	0.010	N/A	N/A	N/A	N/A	N/A	N/A
Toluene	mg/kg	0.098	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A
Ethyl Benzene	mg/kg	0.110	N/A	0.120	N/A	N/A	N/A	N/A	N/A	N/A
Xylenes	mg/kg	0.250	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A
Naphthalene (HPLC)	mg/kg	<0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Naphthalene (GC/MS)	mg/kg	N/A	N/A	1.200	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (HPLC)	mg/kg	15.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (GC/MS)	mg/kg	N/A	N/A	3.400	N/A	N/A	N/A	N/A	N/A	N/A
Phenanthrene	mg/kg	N/A	N/A	<0.33	N/A	N/A	N/A	N/A	N/A	N/A
Fluoranthene	mg/kg	N/A	N/A	<0.33	N/A	N/A	N/A	N/A	N/A	N/A
Total Phenols	mg/kg	5.000	N/A	<0.4	N/A	N/A	N/A	N/A	N/A	N/A
Chlorobenzene	mg/kg	<0.005	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	mg/kg	<0.005	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	mg/kg	<0.005	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A
Trichloroethene	mg/kg	<0.005	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A
trans-1,2-Dichloroethene	mg/kg	<0.005	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A

Soil Samples

TABLE 11. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA (CONTINUED).

Location		FPA-05	FPA-G11A	FPA-11	FPA-11	FPA-11	FPA-11	FPA-12	FPA-12	FPA-12
Depth Interval From	ft	15	0.5	1.5	5	9	15	5	10	15
To	ft	15.6	1	2.1	5.6	9.6	15.6	5.6	10.6	15.6
Date Sampled		9/22/92	9/14/92	9/15/92	9/15/92	9/15/92	9/15/92	9/15/92	9/15/92	9/15/92
Total Petroleum Hydrocarbon	mg/kg	12	4700	22000	490	4200	33	220	790	76
Benzene	mg/kg	N/A	<0.025	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A
Toluene	mg/kg	N/A	<0.025	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A
Ethyl Benzene	mg/kg	N/A	<0.025	N/A	N/A	0.032	N/A	N/A	0.013	N/A
Xylenes	mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A
Naphthalene (HPLC)	mg/kg	N/A	N/A	N/A	N/A	<0.05	N/A	N/A	<0.05	N/A
Naphthalene (GC/MS)	mg/kg	N/A	<0.33	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (HPLC)	mg/kg	N/A	N/A	N/A	N/A	<0.05	N/A	N/A	<0.05	N/A
2-Me-Naphthalene (GC/MS)	mg/kg	N/A	0.930	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Phenanthrene	mg/kg	N/A	<0.33	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fluoranthene	mg/kg	N/A	<0.33	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Phenols	mg/kg	N/A	<1	N/A	N/A	<1	N/A	N/A	<1	N/A
Chlorobenzene	mg/kg	N/A	<0.025	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A
1,1,2,2-Tetrachloroethane	mg/kg	N/A	<0.025	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A
Tetrachloroethene	mg/kg	N/A	<0.025	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A
Trichloroethene	mg/kg	N/A	<0.025	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A
trans-1,2-Dichloroethene	mg/kg	N/A	<0.025	N/A	N/A	<0.005	N/A	N/A	<0.005	N/A

TABLE 11. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA (CONTINUED).

Soil Samples

Location		FPA-13	FPA-13	FPA-13	FPA-20	FPA-20	FPA-20	FPA-B31	FPA-B31	FPA-B31
Depth Interval From	ft	5	10	15	5	10	15	2.5	5.75	8
To	ft	5.6	10.6	15.6	5.6	10.6	15.6	3.5	6.25	9
Date Sampled		9/15/92	9/15/92	9/15/92	9/26/92	9/26/92	9/26/92	9/23/92	9/23/92	9/23/92
Total Petroleum Hydrocarbon	mg/kg	24	76	22	740	190	25	20000	230	5100
Benzene	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	<0.005	N/A	<0.005
Toluene	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	<0.005	N/A	<0.005
Ethyl Benzene	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	1.000	N/A	0.300
Xylenes	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	2.000	N/A	1.200
Naphthalene (HPLC)	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	N/A	N/A	N/A
Naphthalene (GC/MS)	mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	<3.3	N/A	2.600
2-Me-Naphthalene (HPLC)	mg/kg	N/A	N/A	<0.05	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (GC/MS)	mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	39.000	N/A	10.000
Phenanthrene	mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	<3.3	N/A	<.330
Fluoranthene	mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	<3.3	N/A	<.330
Total Phenols	mg/kg	N/A	N/A	<1	N/A	N/A	N/A	<5	N/A	<5
Chlorobenzene	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	<0.005	N/A	<0.005
1,1,2,2-Tetrachloroethane	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	1.000	N/A	0.700
Tetrachloroethene	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	<0.005	N/A	<0.005
Trichloroethene	mg/kg	N/A	N/A	0.019	N/A	N/A	N/A	<0.005	N/A	<0.005
trans-1,2-Dichloroethene	mg/kg	N/A	N/A	<0.005	N/A	N/A	N/A	<0.005	N/A	<0.005

TABLE 11. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA (CONTINUED).

Soil Samples											
Location			FPA-B31	FPA-B31	FPA-B31	FPA-B31	FPA-B32	FPA-B32	FPA-B32	FPA-B32	FPA-B32
Depth Interval	From	ft	10.75	12.75	15.75	18.75	0.25	0.75	9.75	13.75	17
	To	ft	11.25	13.25	16.25	19.25	0.75	1.25	10.25	14.25	22
Date Sampled			9/23/92	9/23/92	9/23/92	9/23/92	9/22/92	9/22/92	9/22/92	9/22/92	9/22/92
Total Petroleum Hydrocarbon		mg/kg	110	180	35	35	2300	1900	55	38	17
Benzene		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A
Toluene		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A
Ethyl Benzene		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A
Xylenes		mg/kg	N/A	<0.010	N/A	N/A	N/A	N/A	<0.010	N/A	N/A
Naphthalene (HPLC)		mg/kg	N/A	<0.05	N/A	N/A	N/A	N/A	<0.05	N/A	N/A
Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (HPLC)		mg/kg	N/A	<0.05	N/A	N/A	N/A	N/A	<0.05	N/A	N/A
2-Me-Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Phenanthrene		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fluoranthene		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Phenols		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	6.000	N/A	N/A
Chlorobenzene		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A
1,1,2,2-Tetrachloroethane		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A
Tetrachloroethene		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A
Trichloroethene		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A
trans-1,2-Dichloroethene		mg/kg	N/A	<0.005	N/A	N/A	N/A	N/A	<0.005	N/A	N/A

Soil Samples

TABLE 11. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA (CONTINUED).

Location			FPA-B32	FPA-B32	FPA-B33	FPA-B33	FPA-B33	FPA-B33	FPA-B33	FPA-B33	FPA-B41
Depth Interval	From	ft	22	29.75	1	3.25	7	9	12.75	17	4
	To	ft	27	30.25	1.5	3.75	8	10	13.25	22	5
Date Sampled			9/22/92	9/22/92	9/23/92	9/23/92	9/23/92	9/23/92	9/23/92	9/23/92	9/22/92
Total Petroleum Hydrocarbon		mg/kg	17	12	500	410	1500	850	750	47	210
Benzene		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025
Toluene		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025
Ethyl Benzene		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025
Xylenes		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	<0.025	N/A	<0.025
Naphthalene (HPLC)		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.000
Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	0.600	N/A	N/A	N/A	0.350
2-Me-Naphthalene (HPLC)		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.300
2-Me-Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	1.500	N/A	N/A	N/A	0.770
Phenanthrene		mg/kg	N/A	N/A	N/A	N/A	<0.33	N/A	N/A	N/A	<.330
Fluoranthene		mg/kg	N/A	N/A	N/A	N/A	<0.33	N/A	N/A	N/A	<.330
Total Phenols		mg/kg	N/A	N/A	N/A	N/A	<1	N/A	N/A	N/A	<5
Chlorobenzene		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025
1,1,2,2-Tetrachloroethane		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025
Tetrachloroethene		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025
Trichloroethene		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025
trans-1,2-Dichloroethene		mg/kg	N/A	N/A	N/A	N/A	<0.005	N/A	<0.025	N/A	<0.025

TABLE 11. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM FUEL PURGE AREA (CONTINUED).

Soil Samples

Location			FPA-B41	FPA-42	FPA-42	FPA-42	FPA-47	FPA-47	FPA-47
Depth Interval	From	ft	10	5	10	15	5	10	15
	To	ft	11	5.6	10.6	15.6	5.6	10.6	15.6
Date Sampled			9/22/92	9/26/92	9/26/92	9/26/92	9/21/92	9/21/92	9/21/92
Total Petroleum Hydrocarbon		mg/kg	6000	130	59	29	22	47	20
Benzene		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
Toluene		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
Ethyl Benzene		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
Xylenes		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
Naphthalene (HPLC)		mg/kg	<0.05	N/A	N/A	N/A	N/A	N/A	N/A
Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (HPLC)		mg/kg	<0.05	N/A	N/A	N/A	N/A	N/A	N/A
2-Me-Naphthalene (GC/MS)		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Phenanthrene		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fluoranthene		mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Phenols		mg/kg	5.000	N/A	N/A	N/A	N/A	N/A	N/A
Chlorobenzene		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
Trichloroethene		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A
trans-1,2-Dichloroethene		mg/kg	<0.025	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 12. OFF-SITE ANALYSIS OF WATER SAMPLES FROM FUEL PURGE AREA.

Water Samples

Location		FPA-B01	FPA-B31	FPA-B32	FPA-B33	FPA-B41	FPA-B45
Depth, below ground surface	ft	wt	wt	wt	wt	wt	wt
Date Sampled		9/23/92	9/23/92	9/23/92	9/23/92	9/23/92	9/23/92
Total Petroleum Hydrocarbon	mg/l	4.9	1.6	1.6	3.3	92	4.9
Benzene	ug/l	<5	<5	N/A	N/A	N/A	N/A
Toluene	ug/l	<5	<5	N/A	N/A	N/A	N/A
Ethyl Benzene	ug/l	<5	<5	N/A	N/A	N/A	N/A
Xylenes	ug/l	<5	<5	N/A	N/A	N/A	N/A
Chlorobenzene	ug/l	<5	<5	N/A	N/A	N/A	N/A
Tetrachloroethene	ug/l	<5	<5	N/A	N/A	N/A	N/A
Trichloroethene	ug/l	<5	<5	N/A	N/A	N/A	N/A
trans-1,2-Dichloroethene	ug/l	<5	<5	N/A	N/A	N/A	N/A

The war's fuel storage tank area was investigated with four LIF-CPT profiles (FPA-43 through FPA-46). The LIF data for these stations were negatively affected by high baselines, which was subsequently corrected. Thus, the LIF-CPT results did not show any "hits". A groundwater and three soil samples were taken at FPA-B45, located directly downgradient of the tanks. Small values for naphthalene and TPH were obtained. These contamination levels were below the detection limit if the LIF-CPT probe.

Wavelength Time Matrices were collected at a majority of the 55 locations tested in the FPA. These WTMs are presented in Appendix K of Volume IV. All the WTMs from FPA were consistent in shape. WTMs from the two plumes identified in the Fuel-Purge turnaround area (FPA-03 and FPA-11) are presented in Figures 41 and 42. Again, these two WTMs are consistent, indicating the same type of contamination (i.e. jet fuels, the LIF can not distinguish between JP-4, and JP-5 as described in Volume I). A typical waveform time decay plot is presented in Figure 43 and indicates consistent shape when compared to the other waveform time decays.

The WTMs from the FPA are significantly different from the WTMs obtained at NTA. Figure 42 presents a typical WTM from FPA-11. This WTM has a peak response at 340 to 350 nm wavelength, whereas, the peak wavelength from the NTA WTMs (see Figure 13) was 360 to 400 nm. These differences are as expected based on analysis during the laboratory validation phase which showed that JP-4 and JP-5 fluoresce at shorter wavelengths than the fuel oil from NTA.

D. FIRE TRAINING AREA 3

1. Background

Fire Training Area 3 (Figure 44) is the current fire training area at Tinker AFB. Tinker AFB has not listed the site within the IRP program as a site to be investigated since some contaminated soil had been removed in 1981 and the facility had been subsequently upgraded with SPCC constructions (6). Consequently, the DT&E investigation constitutes the first invasive environmental investigation at the facility.

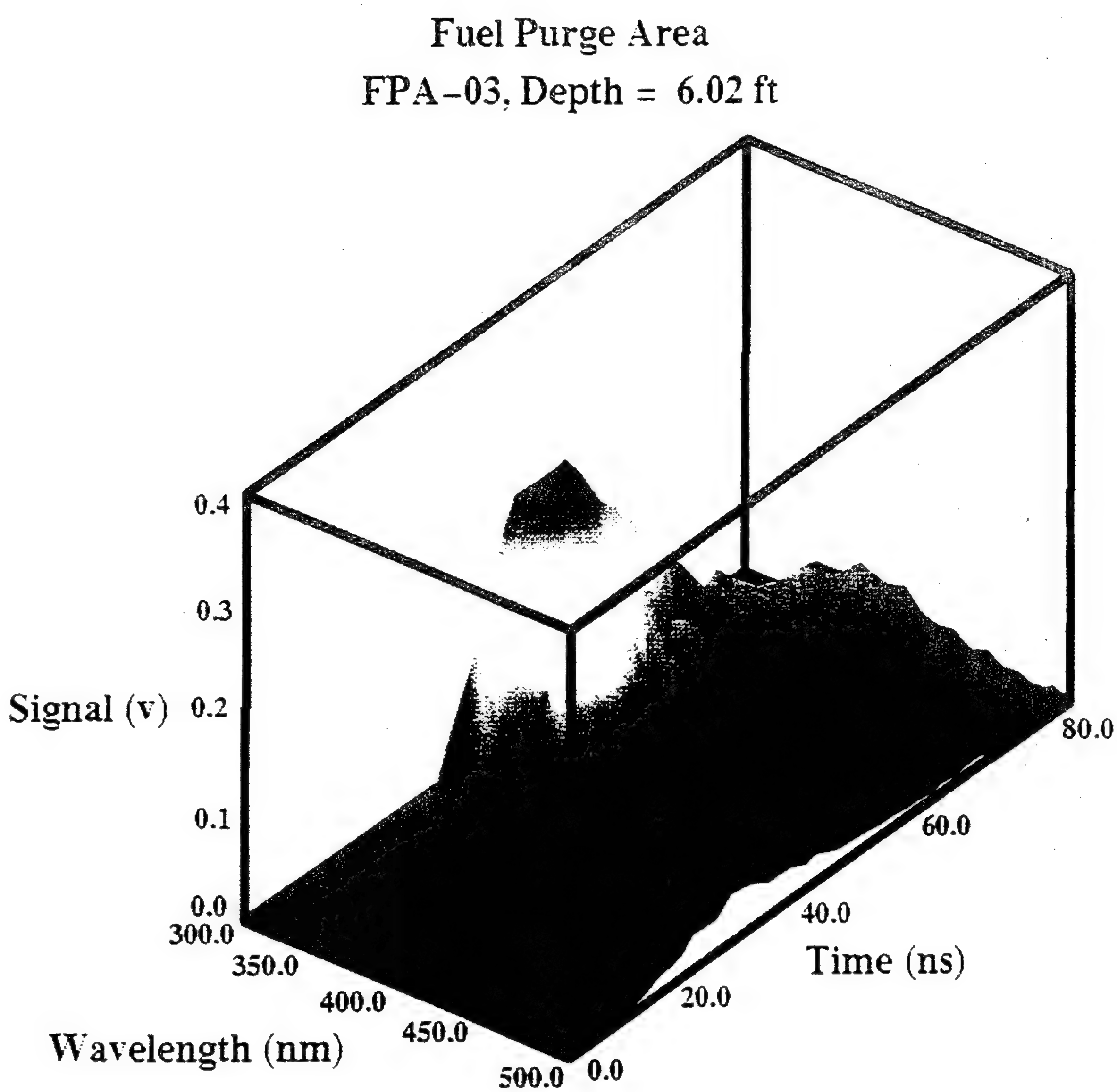


Figure 41. WTM from FPA-03 at a Depth of 6.02 Feet Showing Peak Response from 340 - 360 nm.

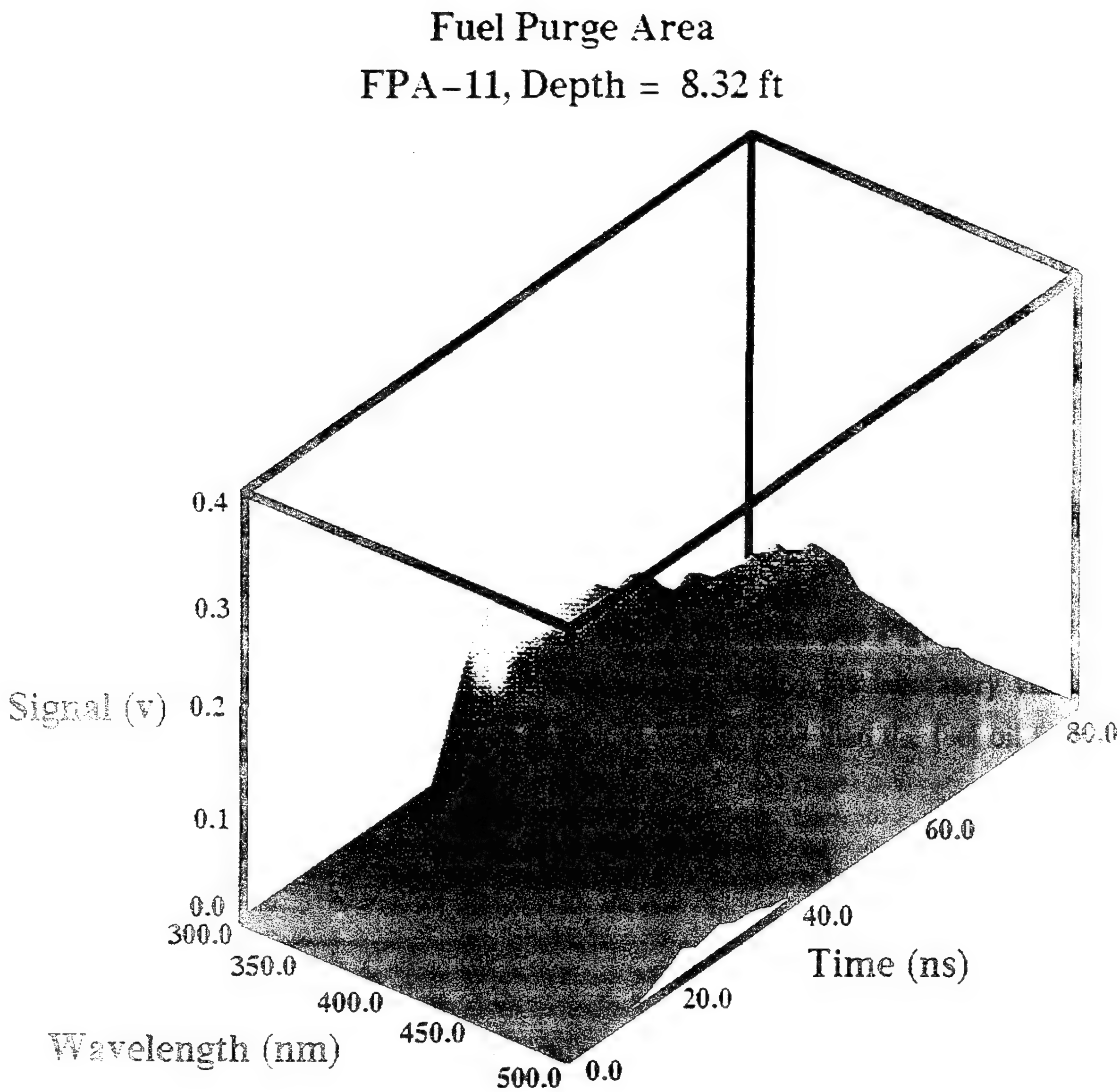


Figure 42. WTM from FPA-11 at a Depth of 8.32 Feet Showing Peak Response from 340 - 360 nm.

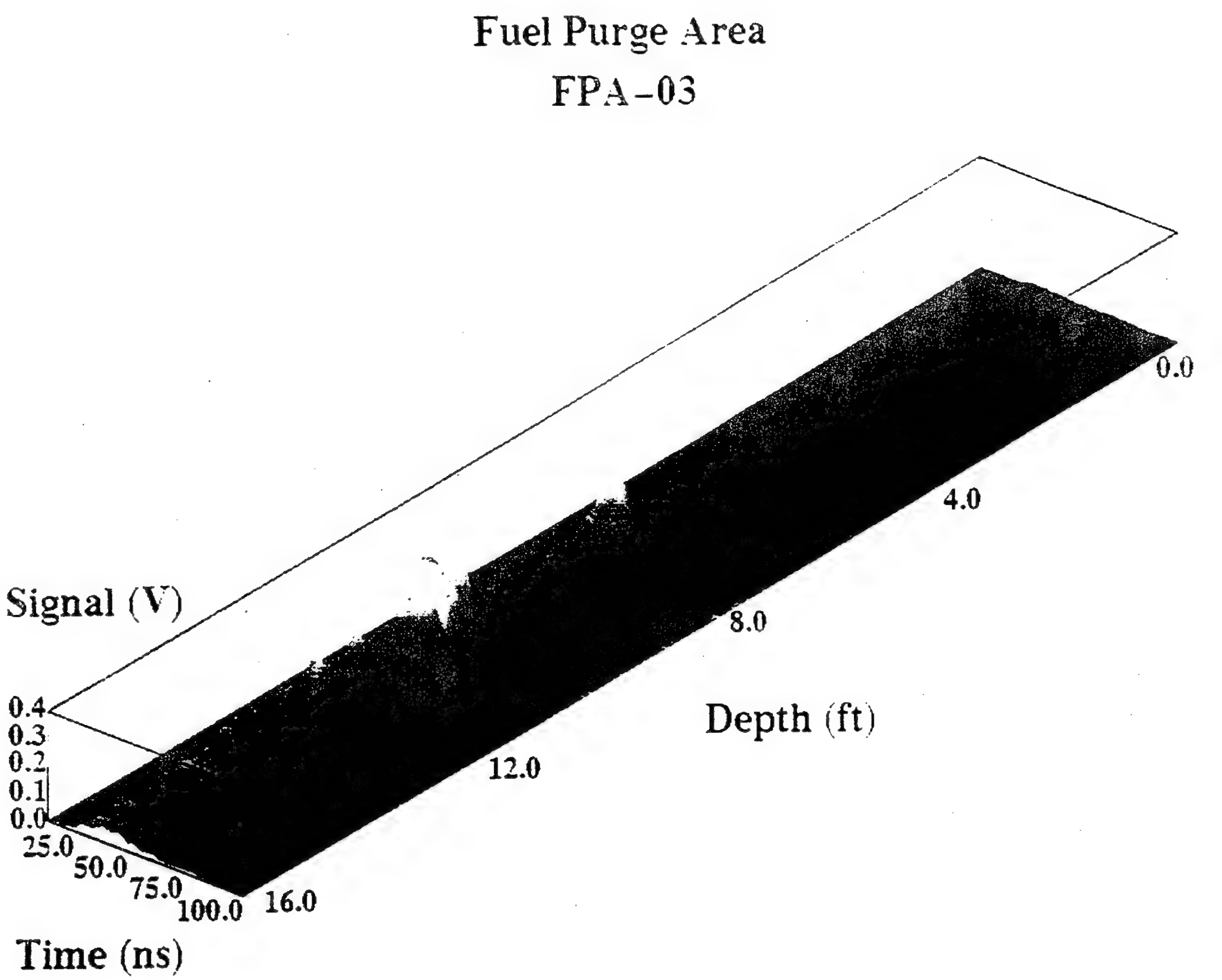


Figure 43. Waveform Time Decays Versus Depth for FPA-03 Showing a Decay of 70 to 80 ns.

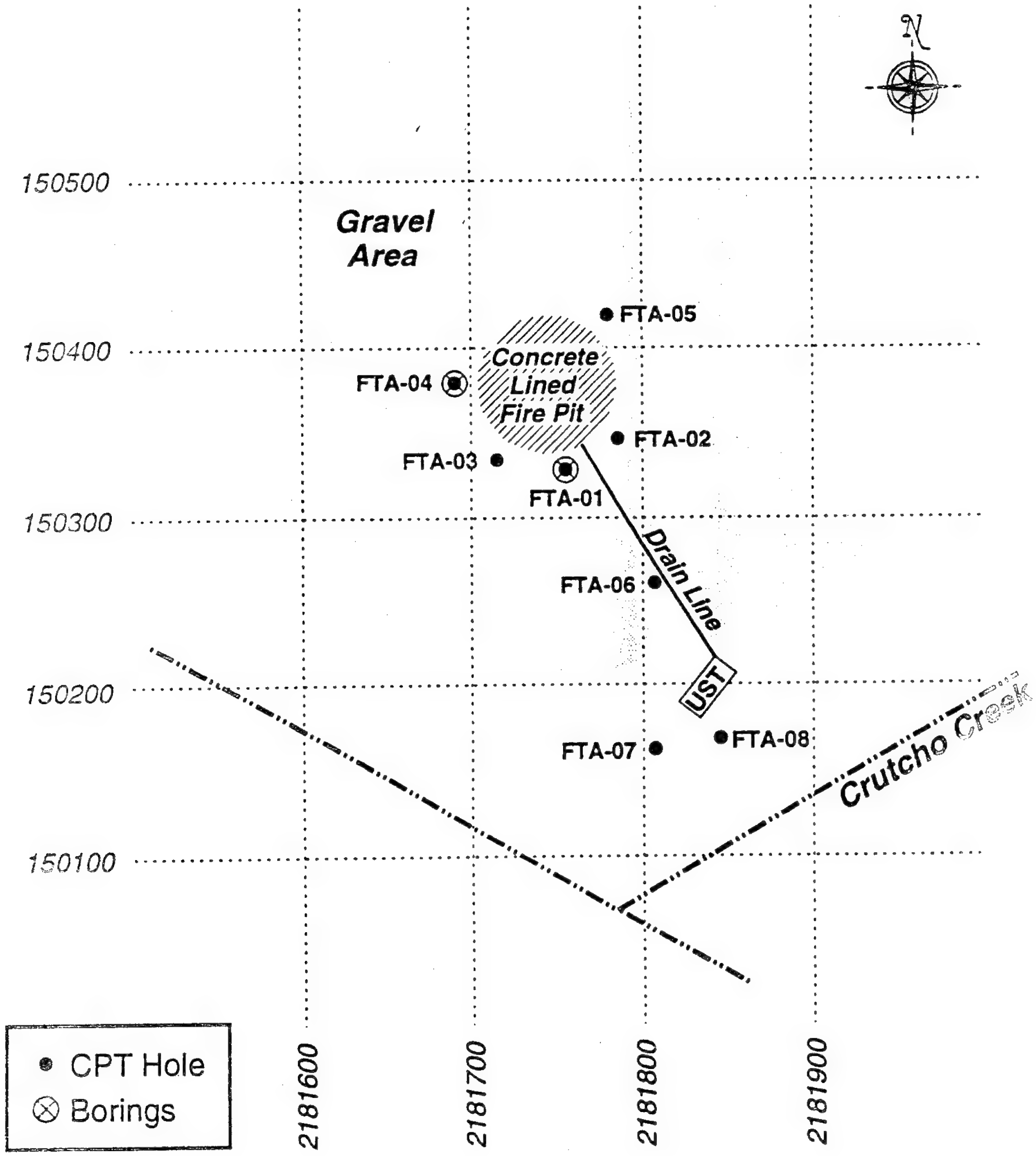


Figure 44. Site Map of the Fire Training Area Showing Fire Pit, Drain Line, and UST.

From 1966 to 1981, the site operated as an unlined, diked pit for Fire Department training activities. The standard procedure for these exercises was to saturate the area with water and then apply and ignite 600 to 700 gallons of contaminated or uncontaminated jet fuel.

A 1981 soil removal project was carried out in response to an overflow incident involving a fuel-laden mixture in the pit. After excavation, a concrete liner and drainage containment system was installed (Figure 44). Information on the site usage conditions and frequency since 1981 was not researched.

Since fire training areas are common to Air Force Installations, some demonstration of AFSCAPS technology at the current Tinker AFB facility was included in the statement of work. LIF-CPT profiling and sampling was performed at Fire Training Area No. 3 to assist Tinker AFB with determination if the site was contaminated or not.

2. Approach and Results

As shown on the site plan, eight LIF-CPT profiles and two drillholes were completed to characterize the area. Six soil samples and one water sample were analyzed for BTEX, TPH, and VOCs.

A typical LIF-CPT profile is presented in Figure 45. The typical soil stratigraphy consists of 2 to 3 feet of a gravelly sand fill material. This material typically classifies as a sand mix and there are indications of fine grained materials at some locations, as evidenced by occasional pore pressure response. The fill material is generally followed by a thin (1-foot thick) clay or clayey silt material. This material is underlain by a consistent silty sand material that extends to the top of a weathered shale. The weathered shale layer slopes steeply from an elevation of 1238 feet at FTA-05 to elevation 1226.5 feet at FTA-07. This situation generally creates a groundwater gradient in the same north to south direction.

Laser induced fluorescence responses above the baseline level were indicated from 3 to 8 feet in FTA-01 and from 3 to 5 feet in the adjacent station FTA-03. All other stations had low LIF readings at or near background. The two locations where responses were recorded appear to be

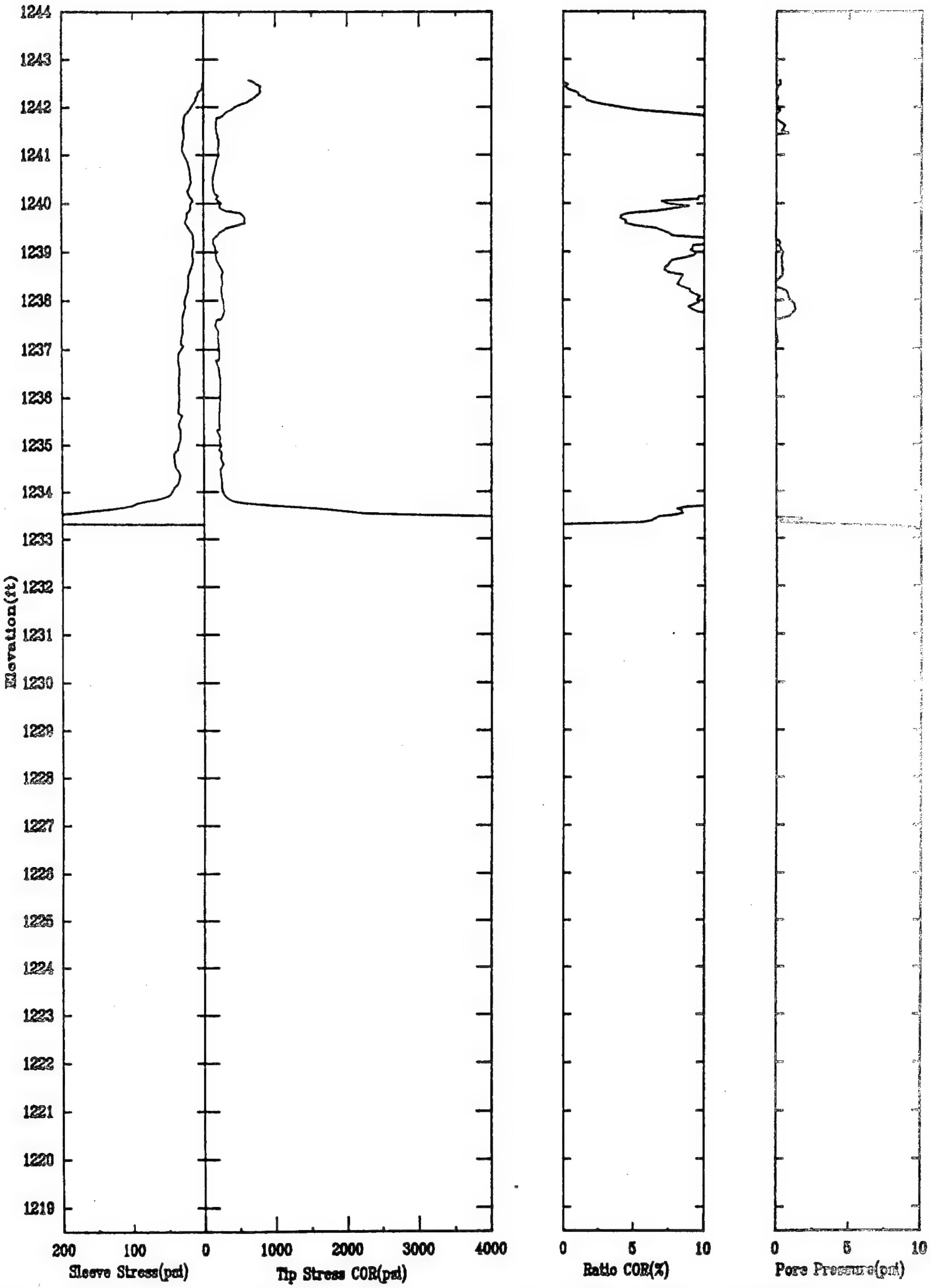


Figure 45. Typical LIF-ECP Profile from the Fire Training Area Showing Data and Soil Stratigraphy.

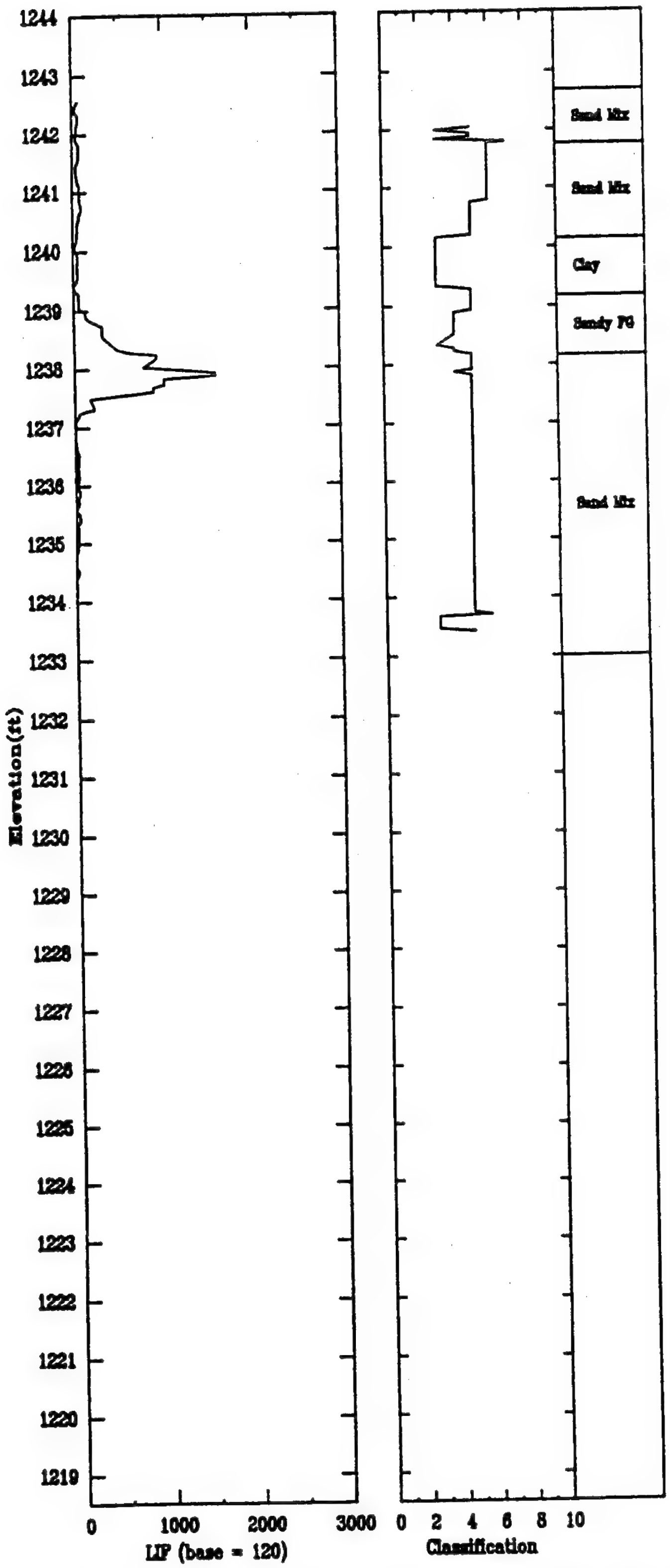


Figure 45. Typical LIF-ECP Profile from the Fire Training Area Showing Data and Soil Stratigraphy (Continued).

hydraulically downgradient of the fire training pit. Moreover, the vertical extent is generally found immediately below a 3-foot thick fill layer surrounding the pit.

Drilling, sampling and analyses at the FPA-B01 and FPA-B04 suggest that the fill is contaminated as well with high TPH and 1,1,2,2-Tetrachloroethane. This is consistent with the reported use of chlorinated solvent-contaminated fuels being used for the firefighting training. Tables 13 and 14 summarize the analytical results for samples obtained from FTA. No benzene was detected in the soil samples tested. A water sample bailed from FTA-B01 did not exhibit any detectable VOCs. The depth to groundwater corresponded closely to the CPT refusal depth of 10.8 feet, at this location. The average CPT refusal depth for the site was 10.3 feet.

Regarding the extent of contamination, the LIF and chemical testing results indicate that the area to the south-southwest of the pit, and perhaps underneath the pit, may have elevated values of BTEX, TPH, and VOCs. Horizontal slices of the LIF results show the extent of the contamination to be limited the soils surrounding FTA-01 and FTA-03, as shown in Figure 46 and tapering off with depth to only around FTA-01 as shown in Figure 47. An isosurface of LIF values greater 950 is presented in Figure 48. This figure clearly shows that the vertical extent of the plume is located between depths of 2 and 5 feet, with the majority of the contamination located in the upper fill material and only minimal seepage into the underlying natural soils. Once again, the contamination appears to be confined to location FTA-01 and nearby soils.

The presence of jet fuel contamination is also confirmed by the WTM shown in Figure 49. The peak response of this WTM is in the range of 340 to 360 nm and gives rise to the conclusion that the contamination is jet fuel. In addition, the waveform time decays shown in Figure 50, decay quickly; similar to those from the FPA area.

E. INDUSTRIAL WASTEWATER TREATMENT PLANT

1. Background

The Industrial Wastewater Treatment Plant (IWTP) maintains several sets of sludge drying beds located adjacent to East Soldier Creek. As shown on Figure 51, the southern set of 6 beds is

TABLE 13. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM FIRE TRAINING AREA.

Soil Samples

Location			FTA-B01	FTA-B01	FTA-B01	FTA-B01	FTA-B04	FTA-B04
Depth Interval	From	ft	1	3.25	6	9.5	1	8
	To	ft	1.5	4	7	10	2	9
Date Sampled			9/26/92	9/26/92	9/26/92	9/26/92	9/28/92	9/28/92
Total Petroleum Hydrocarbon		mg/kg	910	1900	460	12	2300	<10
Benzene		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005
Toluene		mg/kg	<0.005	1.5	0.016	0.150	<0.005	<0.005
Ethyl Benzene		mg/kg	0.280	1.4	0.063	0.250	<0.005	<0.005
Xylenes		mg/kg	1.100	3.4	0.610	1.200	0.080	<0.010
Naphthalene (HPLC)		mg/kg	<0.05	N/A	<0.05	<0.05	<0.05	<0.05
Naphthalene (GC/MS)		mg/kg	N/A	1.2	N/A	N/A	N/A	N/A
2-Me-Naphthalene (HPLC)		mg/kg	<0.05	N/A	<0.05	<0.05	<0.05	<0.05
2-Me-Naphthalene (GC/MS)		mg/kg	N/A	3.2	N/A	N/A	N/A	N/A
Total Phenols		mg/kg	<5	<5	<5	<2	<5	<5
Chlorobenzene		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005
1,1,2,2-Tetrachloroethane		mg/kg	0.700	<0.5	0.130	<0.005	0.160	<0.005
Tetrachloroethene		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005
Trichloroethene		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005
trans-1,2-Dichloroethene		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005
1,2-Dichloroethane		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005
1,1-Dichloroethene		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005
1,1,1-Trichloroethane		mg/kg	<0.005	<0.5	<0.005	0.013	<0.005	<0.005
1,1,2-Trichloroethane		mg/kg	<0.005	<0.5	<0.005	0.024	<0.005	<0.005
Methylene Chloride		mg/kg	<0.005	<0.5	<0.005	<0.005	<0.005	<0.005

TABLE 14. OFF-SITE ANALYSIS OF WATER SAMPLES FROM FIRE TRAINING AREA.

Water Samples

Location		FTA-B01
Depth, below ground surface	ft	wt
Date Sampled		9/26/92
Total Petroleum Hydrocarbon	mg/l	3.3
Benzene	ug/l	<5
Toluene	ug/l	<5
Ethyl Benzene	ug/l	<5
Xylenes	ug/l	<5
Chlorobenzene	ug/l	<5
Tetrachloroethene	ug/l	<5
Trichloroethene	ug/l	<5
trans-1,2-Dichloroethene	ug/l	<5

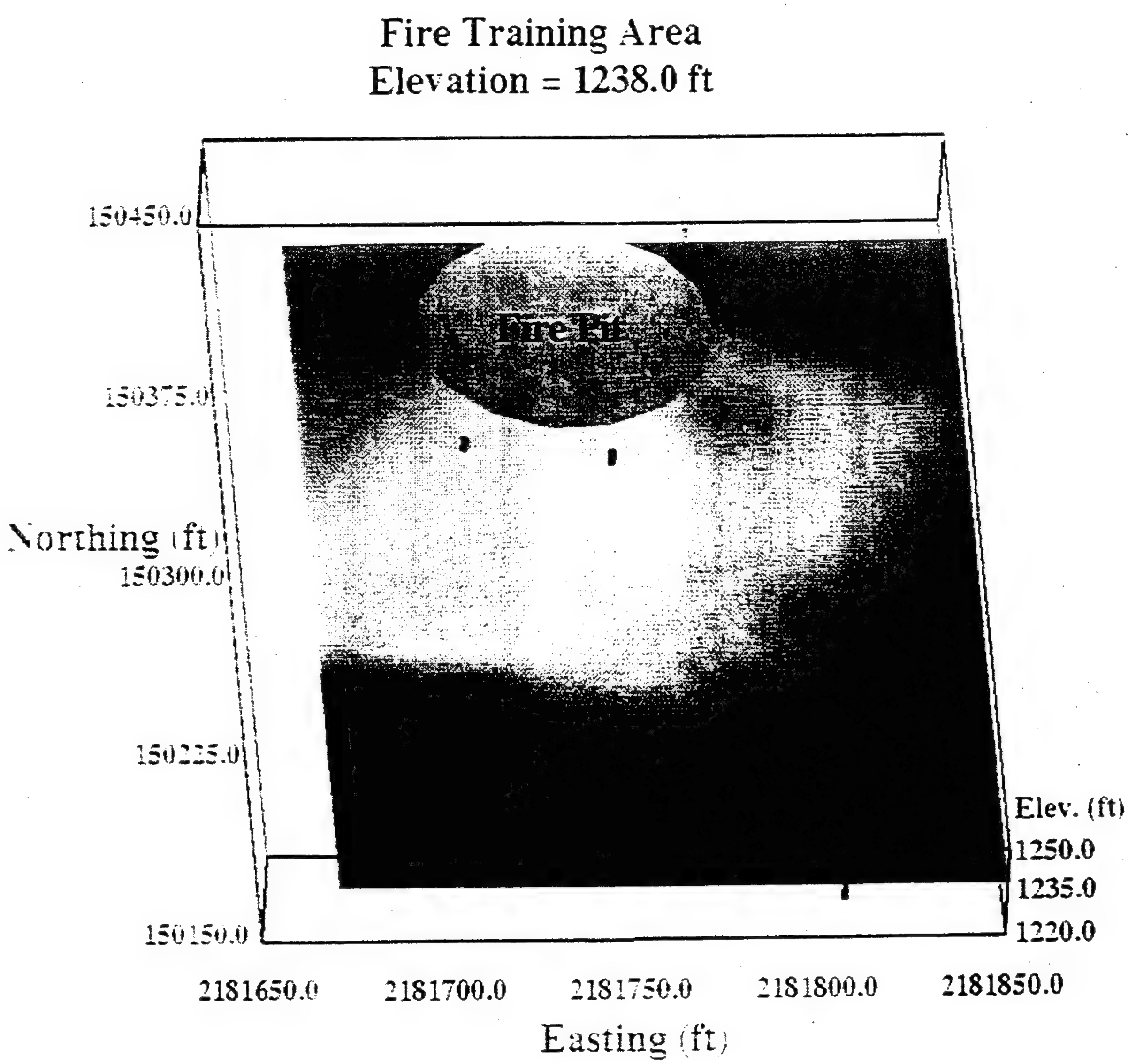


Figure 46. Horizontal Slice of the FTA Area at an Elevation of 1238.0 Feet Showing Contamination on the Southern Edge of the Pit.

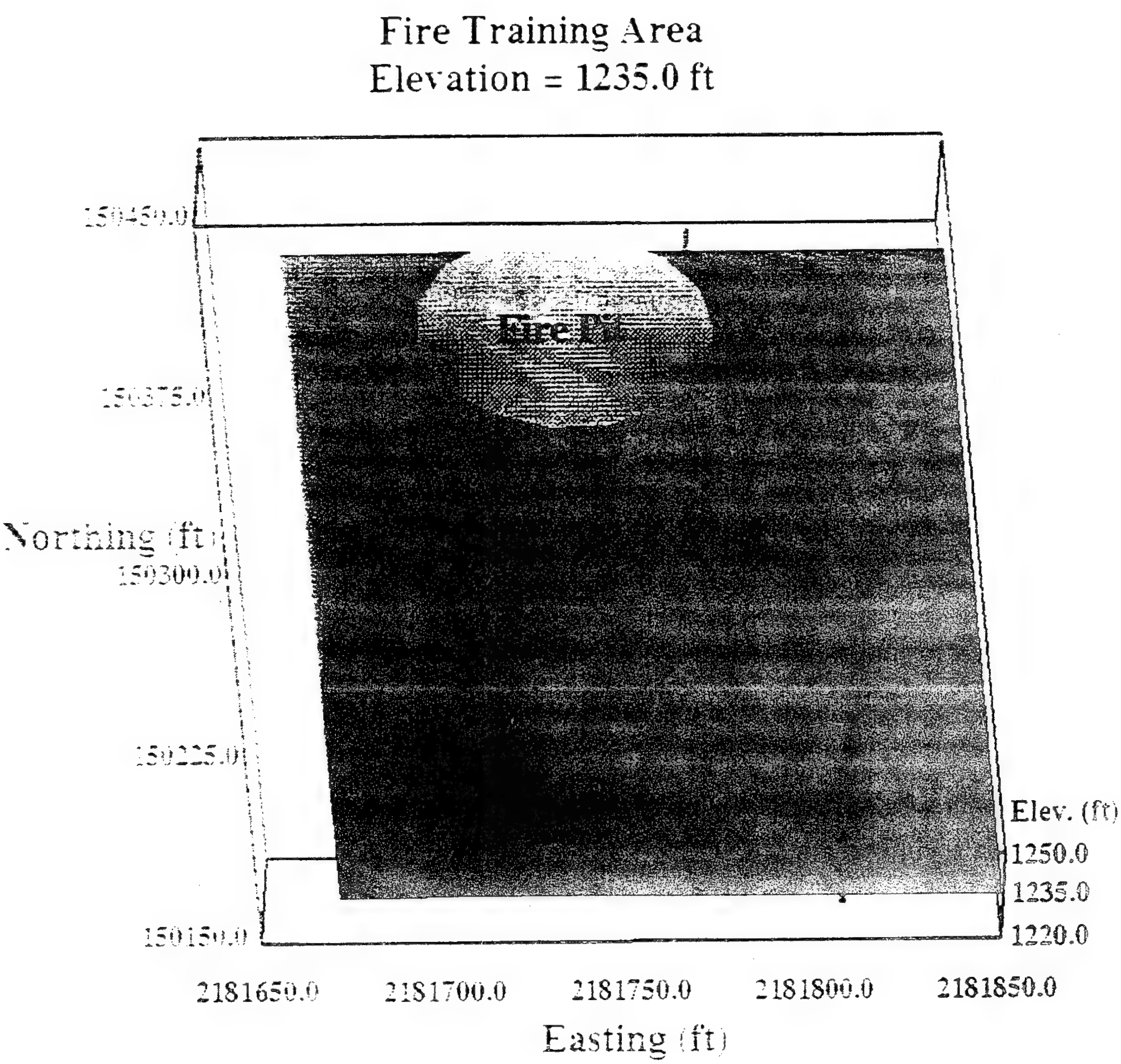


Figure 47. Horizontal Slice of the FTA Area at an Elevation of 1235.0 Feet Showing Contamination Only Around Location FTA-01.

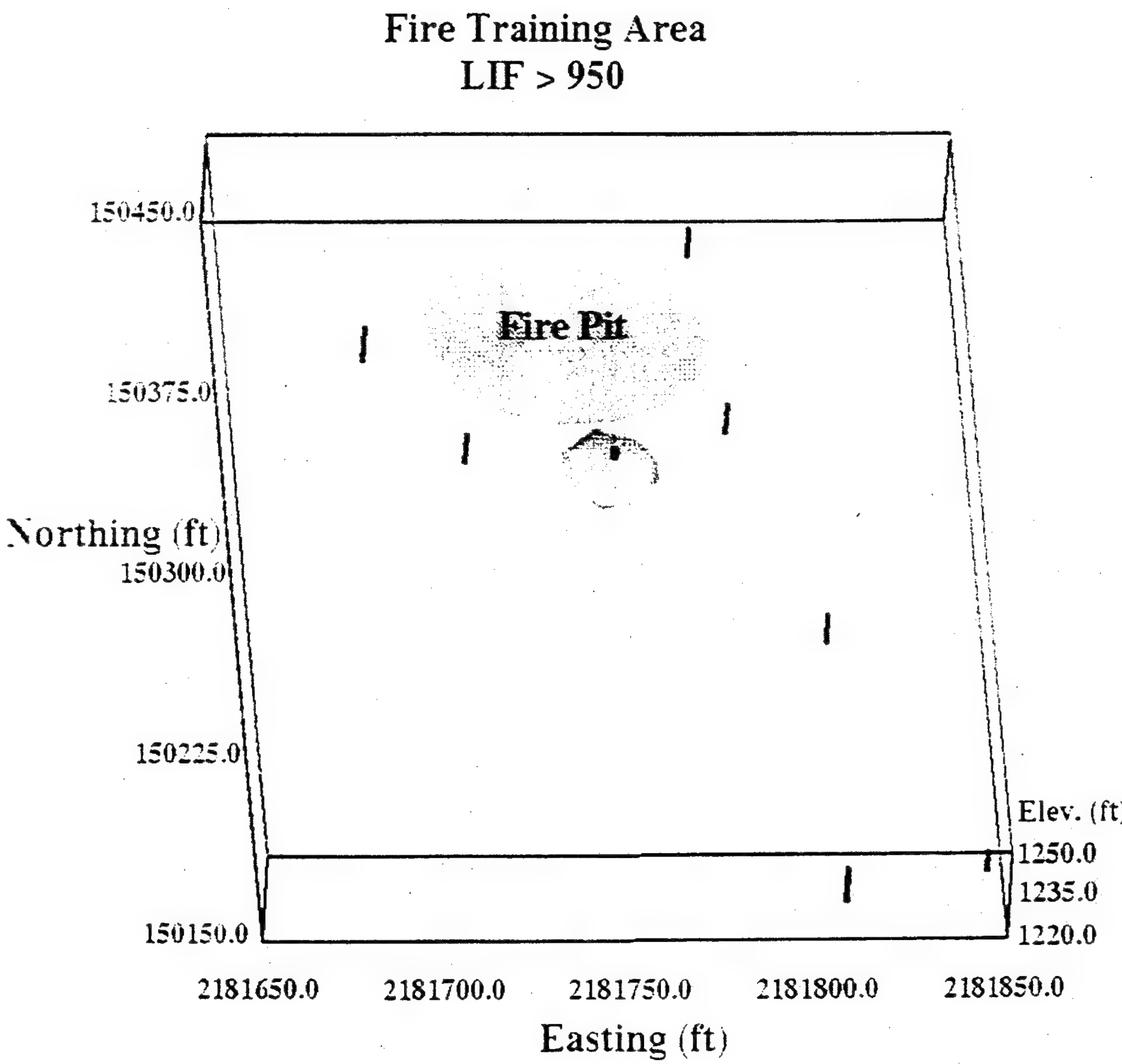


Figure 48. Isosurface of LIF Values Greater Than 950 at the Fire Training Area.

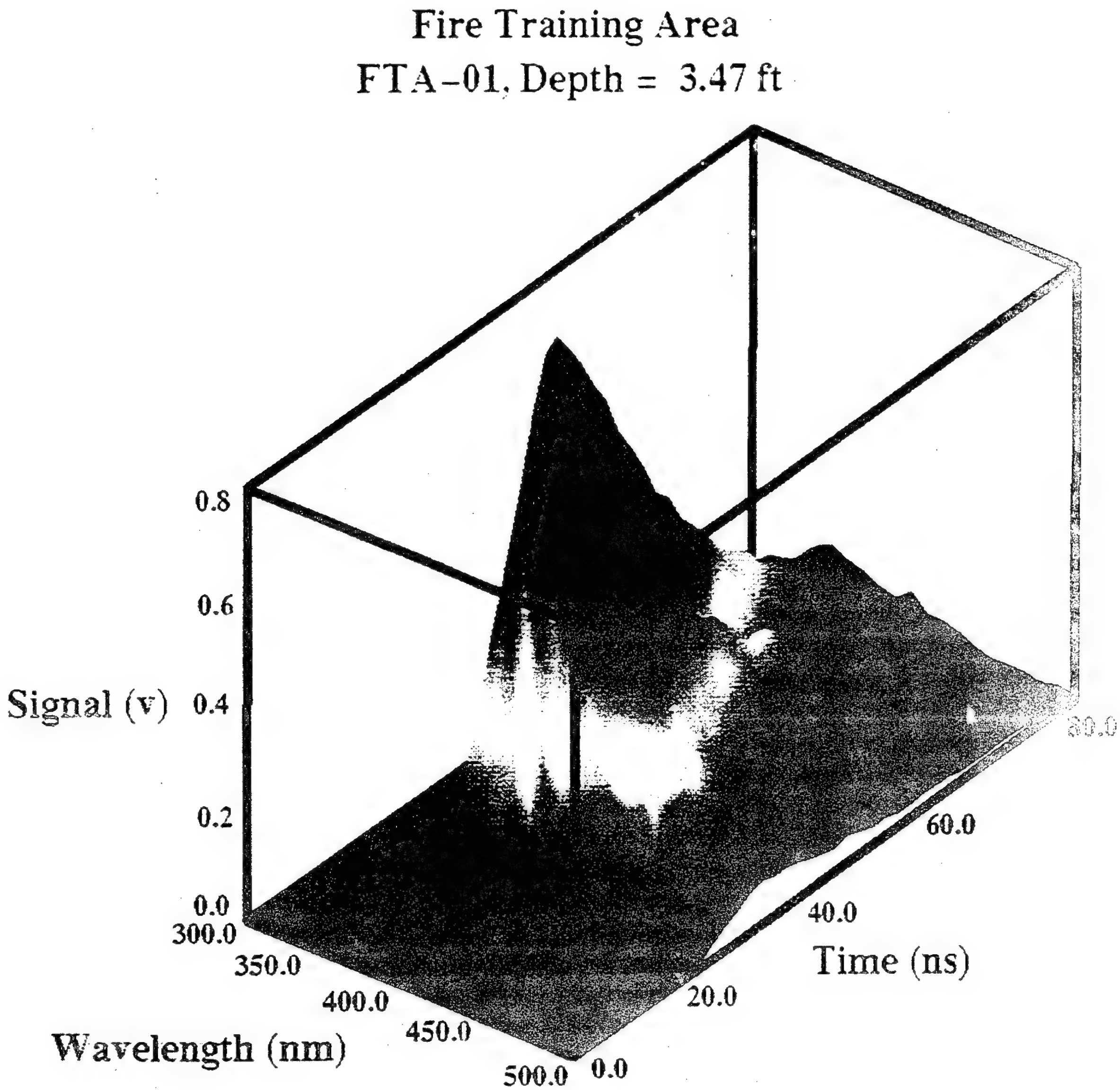


Figure 49. WTM from FTA-01 at a Depth of 3.47 Feet Showing Peak Response from 340 to 360 nm.

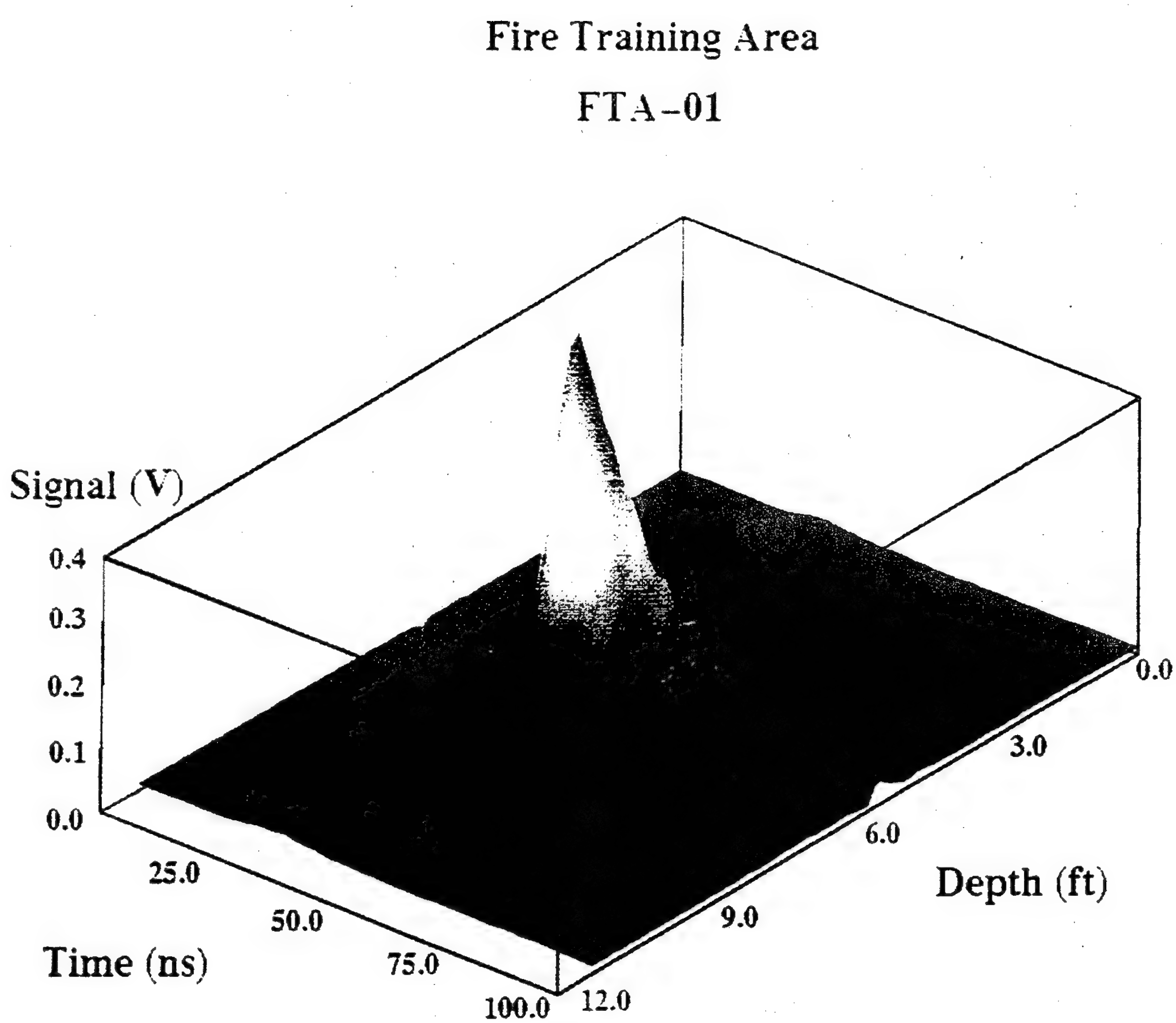


Figure 50. Waveform Decay Versus Depth for FTA-01 Showing a Consistent Shape with the Same Plots from FPA.

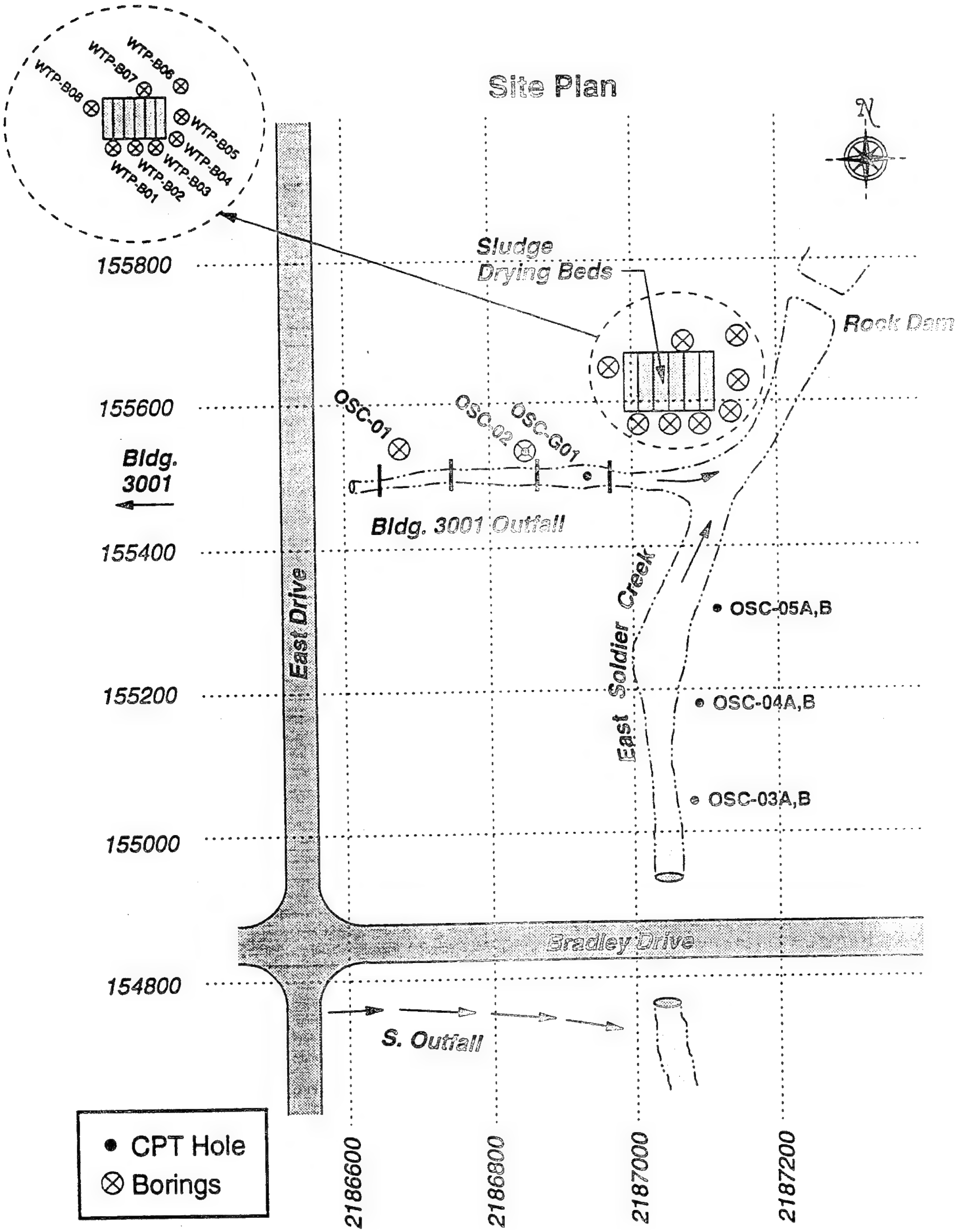


Figure 51. Site Map of the Industrial Wastewater Treatment Plant Along with the Bldg. 3001 Outfall at East Soldier Creek.

a potential IRP candidate site and was included as a subject site within the DT&E. Removal of the beds is planned as an interim remedial action for this site. No background information was readily available for this test area.

Sampling and analysis from soil borings immediately adjacent to the sludge drying beds were the main objectives in the scope of work. Drilling was required to characterize the site geology, depth to groundwater, and subsurface environmental quality for this site. Cone penetration testing was not emphasized for this site due to the shallowness of the sandstone (estimated auger/CPT refusal 6 feet) relative to the depth to groundwater (estimated 13 feet), and the lack of suspected fuel contaminants to demonstrate the LIF probe. Metals, volatiles and semi-volatiles are contaminants of concern, as opposed to BTEX and TPH as in the prior three test areas.

2. Approach and Results

Eight borings were completed around the beds as shown on Figure 51. Soil and water samples were taken from the borings, with soil samples taken from about 16 feet in most cases. Water levels were also determined and compared to surface water levels in the outfall and East Soldier Creek.

The generalized stratigraphy for the site, proceeding from top to bottom, is the following: pavement and subgrade (0-1 foot), fill (1-4 feet), sandy clay (4-6 feet) and weathered sandstone or silty fine sand. The depth of fill ranged from about 3 feet on the western end of the beds to about 5 feet on the eastern end, and was a sand-silt-clay mixture. Sandstone generally weathered to a dense silty fine sand was indicated at various depths in the boreholes. Generally, the dense sand layer was noted at depths of 8 to 11 feet. Refusal of the drill bit was obtained at 14 feet at WTP-B05, presumably on sandstone. Some purple and yellow mottling was noted in most of the sandy sections, probably the effect of wastewater leachate. The presence of the fill layer and loose consistency of the basal sands suggested that CPT penetrations could have been deeper than 6 feet.

VC analyses of the water samples (Table 15) indicate that up-gradient stations WTP-B03, B04 and B05 did not have any detectable quantities of chlorinated hydrocarbons using the field GC. High concentrations of 1,1 dichloroethene (1,030 ug/l) and 1,2 dichloroethane (258 ug/l) were found at WTP-B08, and trichloroethene (60 ug/l) at WTP-B02. No predictable pattern in groundwater

TABLE 15. ONSITE ANALYSIS OF WATER SAMPLES FROM THE INDUSTRIAL WASTEWATER TREATMENT PLANT.

Water Samples

Location		WTP-B02W	WTP-B03W	WTP-B04W	WTP-B05W	WTP-B06W	WTP-B07W	WTP-B08W
Depth below ground surface, ft		15.5	14.8	13.4	12.5	11.8	13.3	17.8
Methylene Chloride	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
1,1 Dichloroethene	(ug/L)	9.718	< 4.0	< 4.0	< 4.0	10.676	25.196	1030.421
1,1,1 Trichloroethane	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
1,2 Dichloroethane	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0	257.930
Trichloroethylene	(ug/L)	60.679	< 4.0	< 4.0	< 4.0	< 4.0	8.284	9.447

TABLE 16. ONSITE ANALYSIS OF SOIL SAMPLES FROM THE INDUSTRIAL WASTEWATER TREATMENT PLANT.

Soil Samples

Location		WTP-B01	WTP-B02	WTP-B03	WTP-B04	WTP-B05	WTP-B06	WTP-B07	WTP-B08
Depth Interval From	(ft)	15	15	15	15	13	13	15	15
To	(ft)	16	16	16	16	14	17	16	16
Methylene Chloride	(mg/kg)	<0.020	0.078	<0.020	0.068	0.100	0.077	0.101	0.080
1,1 Dichloroethene	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,1,1 Trichloroethane	(mg/kg)	0.077	0.042	<0.020	<0.020	0.021	<0.020	0.025	0.028
1,2 Dichloroethane	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Trichloroethylene	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020

concentrations was indicated from the water VC results, although it is most likely that the chlorinated compounds emanated from the Outfall as opposed to East Soldier Creek or the sludge-drying beds.

Soils appear to be relatively uncontaminated. Using the field GC (Table 16), VC results for the soils are notably different than the water results. Methylene chloride and 1,1,1-trichloroethane are commonly found at levels less than 0.1 mg/kg, and may be related to laboratory contaminants. Three duplicate laboratory GC/MS analyses for VOCs, in addition to PAHs, had nondetectable limits for all parameters tested.

Tables 17 and 18 present the sample results from ANALAB, which includes a summary of the metals analyses for the same soil samples. Except for arsenic, barium and cadmium, all parameters tested had values below background. Elevated cadmium values are found in all the soil samples. The presence of arsenic is sporadic with highs on the east and west side of the beds. The elevated values of barium are found in WTP-B01 and WTP-B08, which is suggestive of some possible influence from the outfall discharge. Natural sources of barium may exit at the site as well.

F. EAST SOLDIER CREEK AND BLDG. 3001 DRAINAGE OUTFALL

1. Background

East Soldier Creek receives drainage from the east side of Building 3001. The drainage arrives by surface runoff, storm drains and discharge of perched groundwater. Metals such as Chromium, Nickel, and Cadmium and various chlorinated solvents are known to have been discharged to storm drains that flow to East Soldier Creek. Two such outfalls are noted on Figure 51. The presence of contaminated sediments (metals and VOCs) within the creek bed was verified by testing in 1985 and some subsequent sediment removed as hazardous waste. In July of 1987, East Soldier Creek was declared an operable unit of the Building 3001 NPL Site.

The DT&E tested the state of lateral seepage to or from East Soldier Creek and the storm sewer outfall immediately south of the IWTP. The southern outfall was indirectly addressed in this study. Since the northern outfall contained bodies of water behind a series of four dikes, this area

TABLE 17. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM THE INDUSTRIAL WASTEWATER TREATMENT PLANT.

Soil Samples

Location		WTP-B01	WTP-B02	WTP-B03	WTP-B04	WTP-B05	WTP-B06	WTP-B07	WTP-B08
Depth Interval From	ft	15.5	15.5	15.5	15.5	13.5	13	15.5	15.5
To	ft	16.5	16.5	16.5	16.5	14.5	17	16.5	16.5
Date Sampled		9/24/92	9/24/92	9/24/92	9/25/92	9/25/92	9/25/92	9/25/92	9/25/92
Benzene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
Toluene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
Ethyl Benzene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
Xylenes	mg/kg	N/A	N/A	N/A	<0.010	N/A	<0.010	N/A	<0.010
Semi-Volatiles (8270)*	mg/kg	ND	ND	ND	ND	ND	ND	ND	ND
Total Phenols	mg/kg	<1	<5	<5	<2	<5	<5	<5	<5
Chlorobenzene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
1,1,2,2-Tetrachloroethane	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
Tetrachloroethene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
Trichloroethene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
trans-1,2-Dichloroethene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
1,2-Dichloroethane	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
1,1-Dichloroethene	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
1,1,1-Trichloroethane	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
1,1,2-Trichloroethane	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
Methylene Chloride	mg/kg	N/A	N/A	N/A	<0.005	N/A	<0.005	N/A	<0.005
Total Arsenic	mg/kg	1	<1.0	<1.0	2	4	5	<1.0	4
Total Barium	mg/kg	580	230	200	260	190	150	58	630
Total Cadmium	mg/kg	3	3	3	3	2	5	0.8	4
Total Chromium	mg/kg	13	11	11	12	7	16	3	17
Total Mercury	mg/kg	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	0.4
Total Nickel	mg/kg	8.8	7.6	8.6	9.8	4.3	3.8	2	13
Total Lead	mg/kg	4	4	5	4	2	9	1	6
Total Zinc	mg/kg	15	15	16	17	6.6	7.1	2.6	20

* Refer to lab reports for parameters and detection limits

TABLE 18. OFF-SITE ANALYSIS OF WATER SAMPLES FROM THE INDUSTRIAL WASTEWATER TREATMENT PLANT.

Water Samples

Location		WTP-B04	WTP-B06
Depth, below ground surface	ft	wt	wt
Date Sampled		9/26/92	9/26/92
Benzene	ug/l	<5	<5
Toluene	ug/l	<5	<5
Ethyl Benzene	ug/l	<5	<5
Xylenes	ug/l	<5	<5
Chlorobenzene	ug/l	<5	<5
Tetrachloroethene	ug/l	<5	<5
Trichloroethene	ug/l	<5	<5
trans-1,2-Dichloroethene	ug/l	29	37
1,2-Dichloroethane	ug/l	<5	<5
1,1 Dichloroethene	ug/l	<5	<5
1,1,1-Trichloroethane	ug/l	<5	<5
1,1,2-Trichlorethane	ug/l	<5	<5
Methylene Chloride	ug/l	<5	<5

is a potential recharge source to the perched aquifer and/or East Soldier Creek. Alternatively, the outfall may receive phreatic seepage discharging from the perched lenses. Soil borings and media sampling are required to verify the hydrogeologic conditions in the area of the outfall. Possible lateral contaminant migration from East Soldier Creek may be addressed by sampling along the east bank of East Soldier Creek. A shallow piezometer located between Bradley Drive and the Building 3001 Outfall indicates a perched groundwater flow toward the creek (7).

2. Approach and Results

A combination of CPT and drilling was used to address the outfall and East Soldier Creek Area. The results of the IWTP field work also contributes to the understanding of the local hydrogeology along the outfall and East Soldier Creek.

Two drill holes (located at OSC-01 and OSC-02) were accomplished along the north side of the outfall; the holes were completed to a level 5 feet below the adjacent diked ponds in the outfall. Water in these holes were not stabilized prior to grouting, but moisture conditions suggested that the ponds were significantly higher than the perched groundwater level. This was consistent with observations at the IWTP. As given in Table 19, samples at the base of these two drill holes showed background levels except for slightly elevated levels of arsenic and cadmium in OSC-B02. These metals were high in several holes near the IWTP as well.

A sediment grab sample (OSC-G01) was taken from the outfall bottom at a depth from 0.1 to 0.5 feet. The high metal content suggested in the background review was found for the outfall, suggesting the outfall is a contaminant route for waste disposed during past industrial activities at Building 3001. Metals which were 10 to 40 times higher than the background were chromium, nickel, lead, and zinc. Cadmium was almost 400 times the background, making this outfall a likely candidate for the elevated cadmium levels observed at OSC-B02 and the IWTP beds. This would substantiate groundwater transport to the north from the outfall to the shallow groundwater system. From the field GC scan Table 20, no significant VOCs were detected in the three soils samples.

CPT holes were performed at three locations along the east bank of East Soldier Creek, with little information gathered due to a shallow refusal for 2 to 3 feet. A CPT at OSC-02 substantiated that the CPT refusal corresponded with the top of the sandstone (6.8 feet) as shown in Figure 52.

TABLE 19. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM EAST SOLDIER CREEK AREA.

Soil Samples

Location			OSC-B01	OSC-B02	OSC-G01
Depth Interval	From	ft	15.5	10.5	0.1
	To	ft	16.5	11.5	0.5
Date Sampled			9/25/92	9/25/92	9/26/92
Total Phenols		mg/kg	<5	<5	<5
Total Arsenic		mg/kg	<1.0	4	2
Total Barium		mg/kg	32	170	500
Total Cadmium		mg/kg	<0.1	5	390
Total Chromium		mg/kg	5.6	21	800
Total Mercury		mg/kg	<0.05	<0.05	0.4
Total Nickel		mg/kg	3.3	14	300
Total Lead		mg/kg	2	5	320
Total Zinc		mg/kg	4.1	21	340

TABLE 20. ONSITE ANALYSIS OF SOIL SAMPLES FROM EAST SOLDIER CREEK AREA.

Soil Samples

Location			OSC-B01	OSC-B02	OSC-G01
Depth Interval	From	ft	15.5	10.5	0.1
	To	ft	16.6	11.5	0.5
Methylene Chloride		(mg/kg)	0.097	0.022	0.045
1,1 Dichloroethene		(mg/kg)	<0.020	<0.020	<0.020
1,1,1 Trichloroethane		(mg/kg)	0.043	<0.020	<0.020
1,2 Dichloroethane		(mg/kg)	<0.020	<0.020	<0.020
Trichloroethylene		(mg/kg)	<0.020	<0.020	<0.020

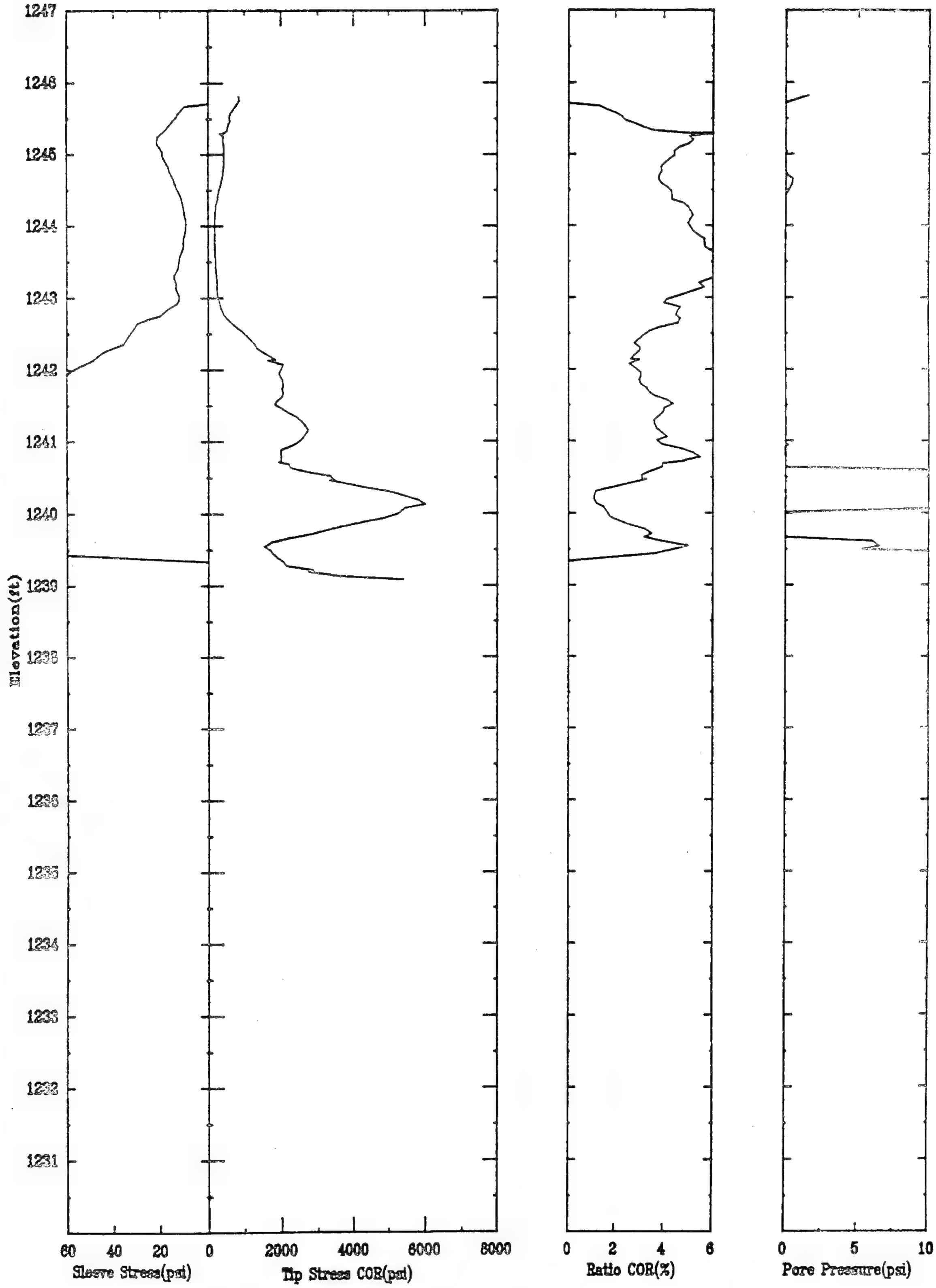


Figure 52. Typical CPT Profile from Along the East Bank of East Soldier Creek Showing Shallow Refusal at the Top of the Sandstone.

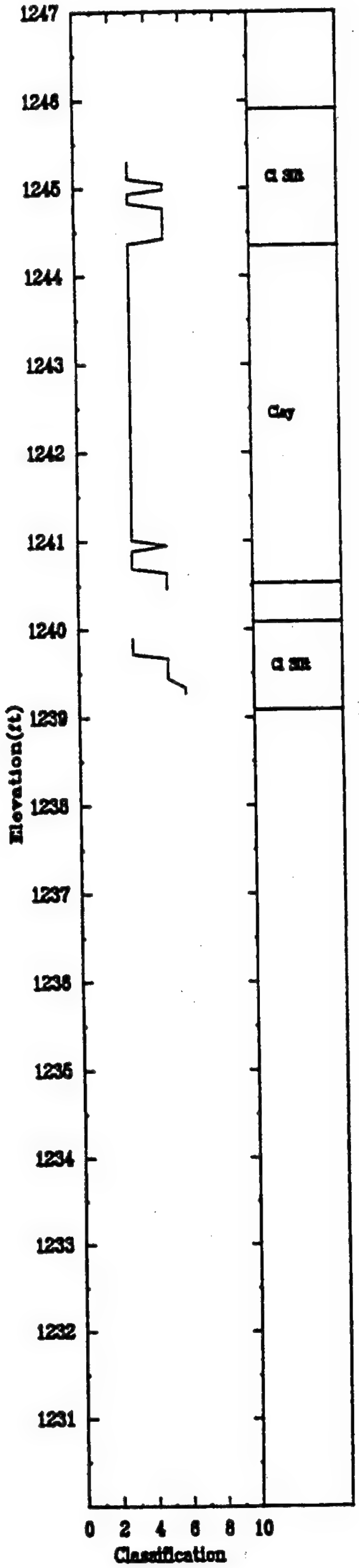


Figure 52. Typical CPT Profile from Along the East Bank of East Soldier Creek Showing Shallow Refusal at the Top of the Sandstone (Continued).

G. LANDFILL 2

1. Background

Landfill 2 is an industrial refuse dump located in the southwestern portion of Tinker AFB. As for all the old landfill sites at Tinker, Landfill 2 is on the Air Force IRP list. Borings completed during initial closure studies in 1989 identified a sludge disposal area in the landfill. Soil gas surveys of Landfill 2 and the contained sludge dump sub-sites were performed in 1990 (8). The shallow gas results showed that the sludge dump was in the vicinity of VC, methane, and petroleum hydrocarbon highs. Landfill 2 possesses an upper groundwater bearing zone that tends to saturate the waste, increasing the potential for the spread of groundwater contamination. To investigate the nature and extent of the sludge dump further, Tinker AFB requested that the area be addressed using CPT during the DT&E.

Figure 53 illustrates the northeast portion of Landfill 2 with Sludge Dump L2-11 highlighted. Piezometer L2-11 was drilled and installed in 1989. Sludge from 13 to 18 feet was unexpectedly encountered in the boring. Chemical analyses of the sludge material indicated high concentrations of industrial solvents and hydrocarbons. In 1990, six follow-up piezometers were installed; 21 borings using an auger were used during that subsurface investigation. VOCs, alpha and beta radiation, and metals were detected in the piezometer water samples. These piezometers and Well MW-86A were surveyed as part of the DT&E.

2. Approach and Results

Eleven CPT profiles were performed in Landfill 2 near Sludge Dump L2-11. The average depth of penetration was 10.4 feet, which was significantly above the 18-foot depth determined for the sludge dump at L2-11 and also above the average depth of the other piezometer that ranged from 13 to 22 feet deep. The DT&E plan stated that the in-situ clays, estimated to be about 15 feet, were not to be penetrated. Consequently, a "soft" refusal determination was used. The CPT refusal surface had a 5 percent northerly gradient.

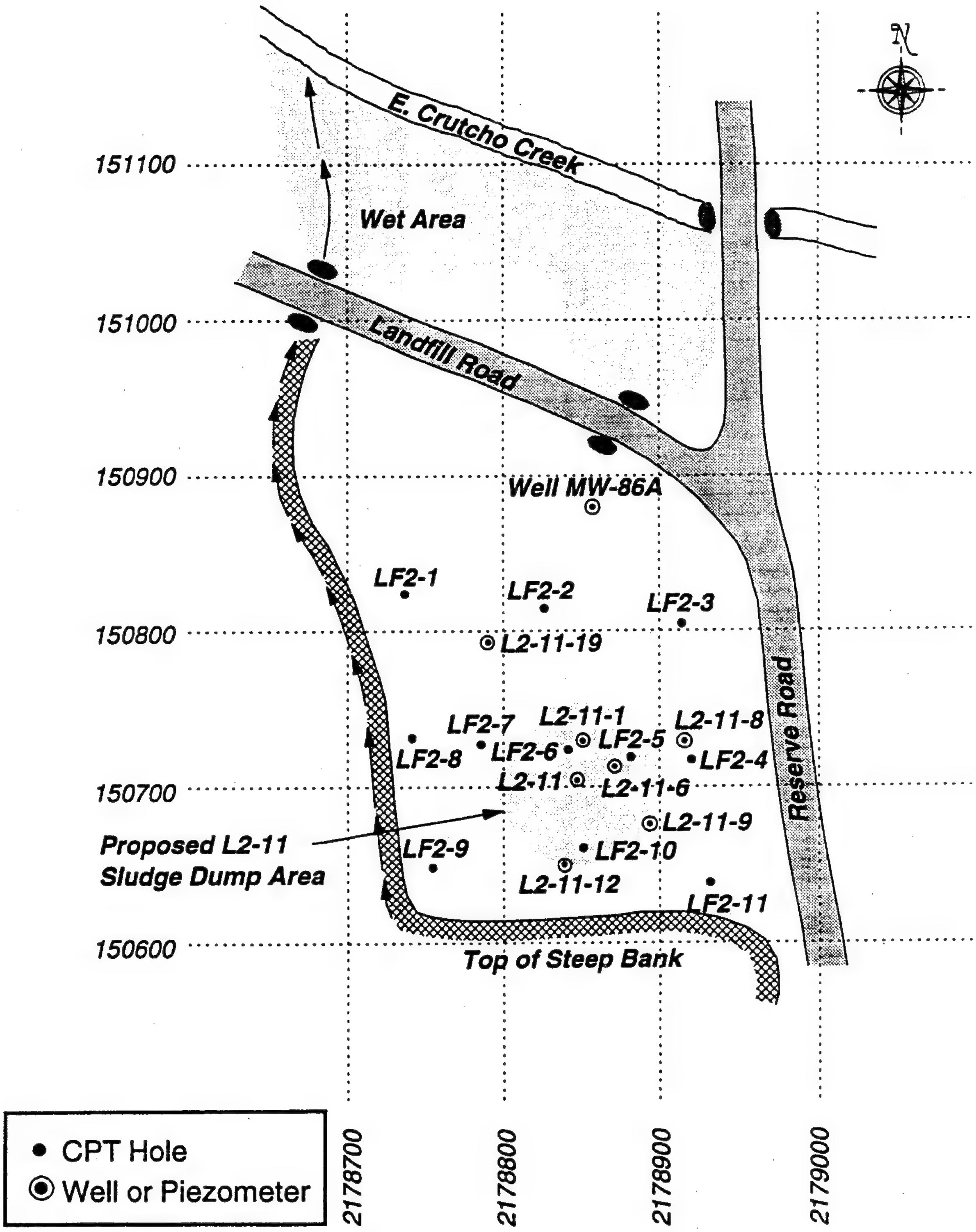


Figure 53. Site Map of the Northeast Portion of Landfill No. 2 with Sludge Dump L2-11 Highlighted.

Since the penetrations were conducted in refuse materials, the interpretation of the CPT, especially in terms of soil stratigraphy, are difficult to perform. The penetration profile from Landfill 2 location 6 is presented in Figure 54. This penetration was conducted within the sludge dump area. The tip and sleeve stresses indicate several different layers of materials, as might be expected in a landfill where the waste is placed in layers, covered with soil, and compacted by traffic. The interesting aspect though, is that excess pore pressures were commonly generated, indicating moist soil conditions, even above the depths of the proposed sludge.

LIF profiling was conducted during penetrations LF2-01 to LF2-07 to identify any zone of petroleum-type contamination. After penetration LF2-07 the LIF became inoperable, and was not used for the completion of the testing at Landfill 2. None of the profiles had LIF values above the baseline values, indicating that fuel-type contamination was detected by the LIF-CPT probe in the materials tested.

CPT samples were taken at LF2-05, LF2-06, LF2-07, and LF2-10. The samples were composited from two consecutive sampling pushes at each station, retrieving approximately 4 feet of landfill material. Most of the pushes resulted in poor recovery due to the unconsolidated nature of the push. The samples were mainly comprised of a red to brown sandy clay to silty sand. Minor debris such as glass and ash was recovered. No black organic sludge material was sampled in the area identified as the sludge dump.

The soil samples were void of any VOCs or semivolatiles, as presented in Tables 21 and 22. However, heavy metals were found in high concentrations in all the soil samples. Most notable were arsenic, barium, cadmium, lead and zinc. The high metals content is typical of ash or sludge materials.

Water samples from the existing piezometers were taken and analyzed for VOCs. Only the original piezometer (L2-11) had detectable quantities: benzene and toluene were measured at 168 ug/l and 27 ug/l, respectively (see Table 23 and 24).

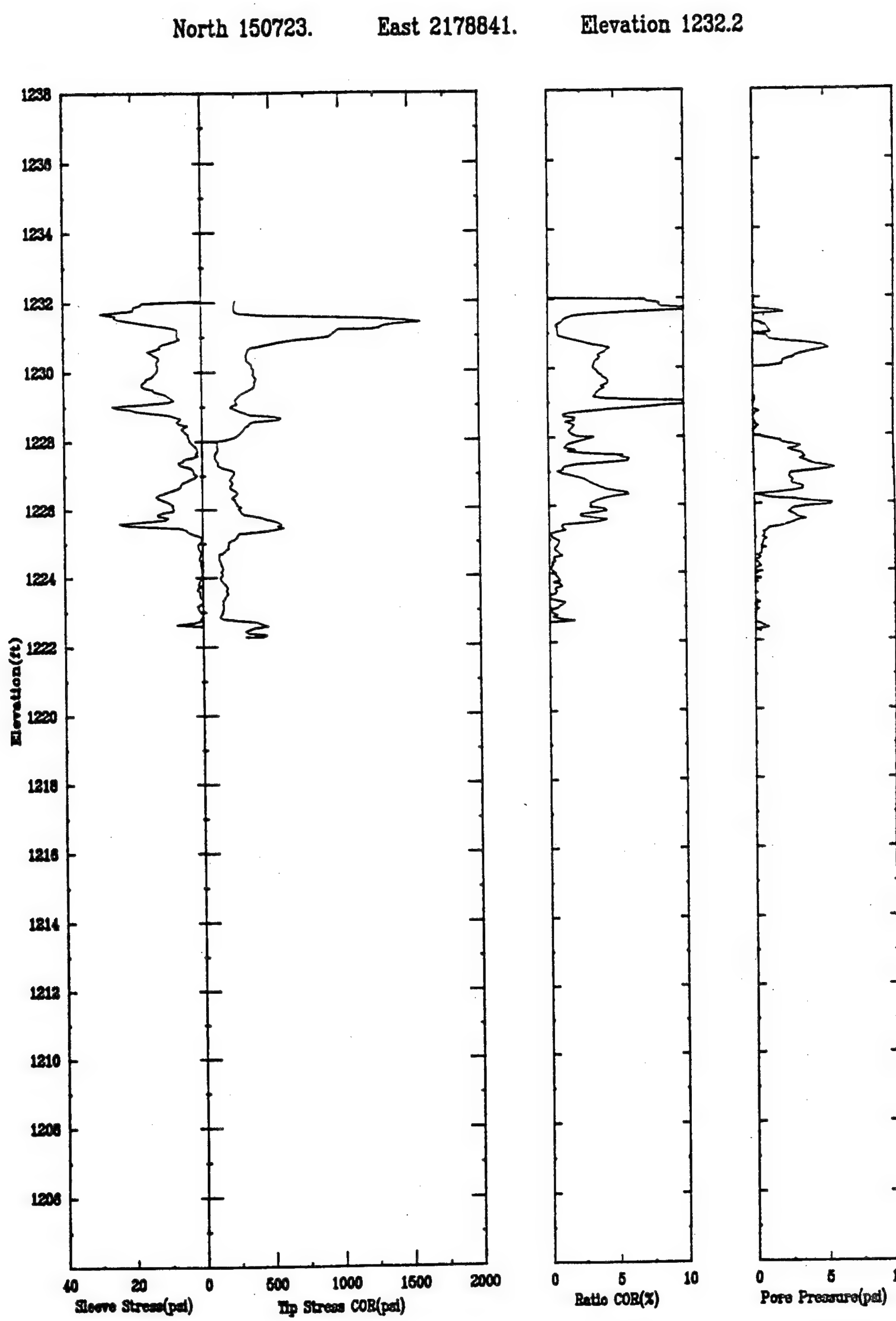


Figure 54. LIF-CPT Profile from LF2-06 Showing Typical Layering of the Landfill Materials.

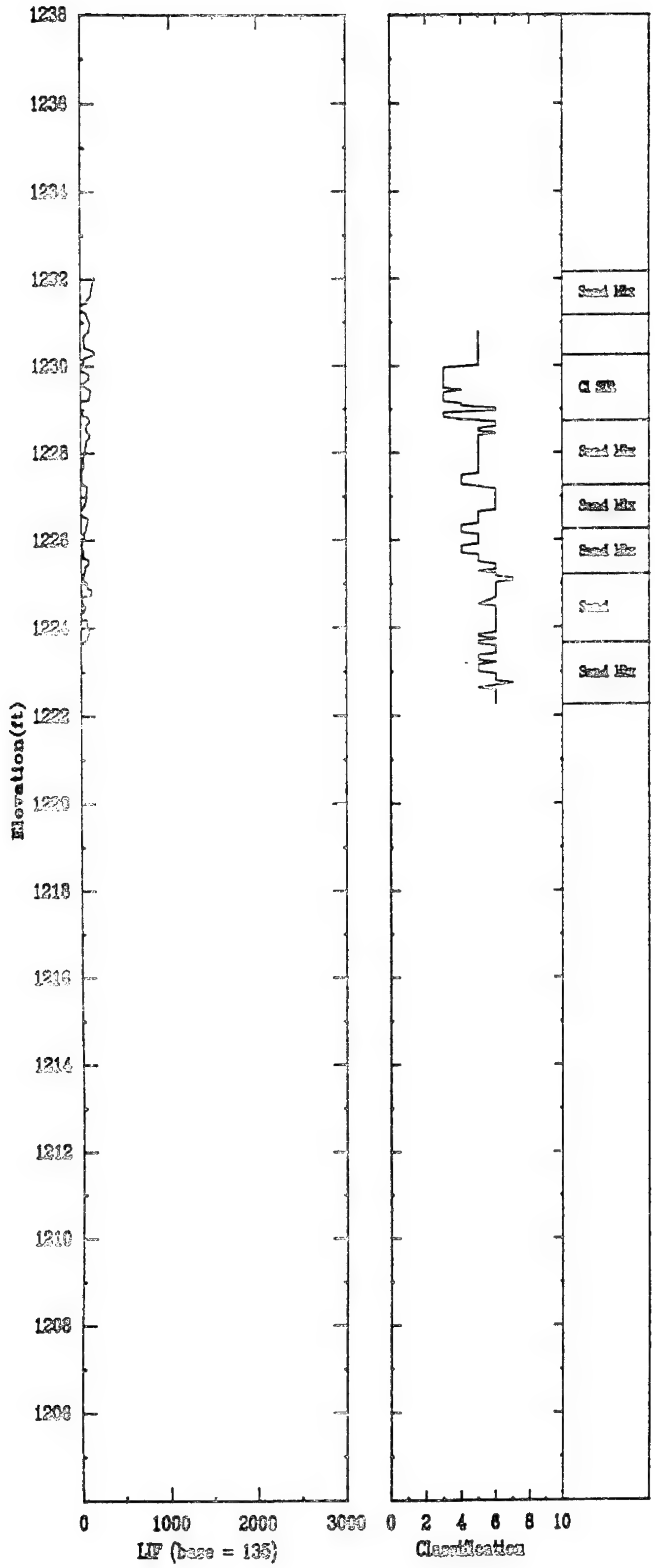


Figure 54. LIF-CPT Profile from LF2-06 Showing Typical Layering of the Landfill Materials (Concluded).

Soil Samples

TABLE 21. ONSITE ANALYSIS OF SOIL SAMPLES FROM LANDFILL NO. 2.

Location		LF2-07	LF2-07	LF2-05	LF2-05	LF2-06	LF2-06	LF2-10	LF2-10
Depth Interval From	(ft)	8	10	5	7	7.5	9.5	4	6
To	(ft)	9.6	11.6	6.6	8.6	9.1	11.1	5.6	7.6
Methylene Chloride	(mg/kg)	0.045	0.020	0.021	0.024	0.044	<0.020	0.036	0.049
1,1 Dichloroethene	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,1,1 Trichloroethane	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	0.056	0.024	0.023
1,2 Dichloroethane	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Trichloroethylene	(mg/kg)	<0.020	<0.020	0.000	<0.020	<0.020	<0.020	<0.020	<0.020

TABLE 22. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM LANDFILL NO. 2.

Soil samples

Location		LF2-05	LF2-06	LF2-07	LF2-10
Depth Interval From	ft	5	7.5	8	6
To	ft	8.6	11.1	11.6	7.6
Date Sampled		10/2/92	10/2/92	10/2/92	10/2/92
Total Petroleum Hydrocarbon	mg/kg	160	430	370	140
Benzene	mg/kg	<0.005	<0.005	N/A	<0.005
Toluene	mg/kg	<0.005	0.053	N/A	<0.005
Ethyl Benzene	mg/kg	<0.005	<0.005	N/A	<0.005
Xylenes	mg/kg	<0.010	<0.010	N/A	<0.010
Semi-Volatiles (8270)*	mg/kg	ND	ND	ND	ND
Total Phenols	mg/kg	<5	<5	<5	<5
Chlorobenzene	mg/kg	<0.005	<0.005	N/A	<0.005
1,1,2,2-Tetrachloroethane	mg/kg	<0.005	<0.005	N/A	<0.005
Tetrachloroethene	mg/kg	<0.005	<0.005	N/A	<0.005
Trichloroethene	mg/kg	<0.005	<0.005	N/A	<0.005
trans-1,2-Dichloroethene	mg/kg	<0.005	<0.005	N/A	<0.005
1,2-Dichloroethane	mg/kg	<0.005	<0.005	N/A	<0.005
1,1-Dichloroethene	mg/kg	<0.005	<0.005	N/A	<0.005
1,1,1-Trichloroethane	mg/kg	<0.005	<0.005	N/A	<0.005
1,1,2-Trichloroethane	mg/kg	<0.005	<0.005	N/A	<0.005
Methylene Chloride	mg/kg	<0.005	<0.005	N/A	<0.005
Total Arsenic	mg/kg	11	<1.0	2.6	<1.0
Total Barium	mg/kg	790	300	810	1200
Total Cadmium	mg/kg	77	13	16	7.7
Total Chromium	mg/kg	73	2.2	31	25
Total Mercury	mg/kg	0.09	0.09	0.2	<.001
Total Nickel	mg/kg	71	71	34	21
Total Lead	mg/kg	1400	580	300	72
Total Zinc	mg/kg	1900	1000	280	67

* Refer to lab reports for parameters and detection limits

TABLE 23. OFF-SITE ANALYSIS OF WATER SAMPLES FROM LANDFILL NO. 2.

Water Samples

Location		LF2-11	LF2-11-6	LF2-11-9	LF2-11-12	LF2-11-8
Depth below ground surface,	ft	11.7	9.7	12.3	N/A	10.3
Methylene Chloride	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
1,1 Dichloroethene	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
1,1,1 Trichloroethane	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
1,2 Dichloroethane	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0
Trichloroethylene	(ug/L)	< 4.0	< 4.0	< 4.0	< 4.0	< 4.0

TABLE 24. ONSITE ANALYSIS OF WATER SAMPLES FROM LANDFILL NO. 2.

Water Samples

Location		L2-11	L2-11-6	L2-11-9	L2-11-12	L2-11-8
Depth, below ground surface	ft	11.7	9.7	12.3	N/A	10.3
Date Sampled		10/6/92	10/6/92	10/6/92	10/6/92	10/6/92
Benzene	ug/l	168	<5	<5	<5	<5
Toluene	ug/l	27	<5	<5	<5	<5
Ethyl Benzene	ug/l	<5	<5	<5	<5	<5
Xylenes	ug/l	<5	<10	<5	<10	<5
Chlorobenzene	ug/l	<5	<5	<5	<5	<5
Tetrachloroethene	ug/l	<5	<5	<5	<5	<5
Trichloroethene	ug/l	<5	<5	<5	<5	<5
trans-1,2-Dichloroethene	ug/l	<5	<5	<5	<5	<5
1,2-Dichloroethane	ug/l	<5	<5	<5	<5	<5
1,1 Dichloroethene	ug/l	<5	<5	<5	<5	<5
1,1,1-Trichloroethane	ug/l	<5	<5	<5	<5	<5
1,1,2-Trichlorethane	ug/l	<5	<5	<5	<5	<5
Methylene Chloride	ug/l	<5	<5	<5	<5	<5

H. LANDFILL 4

1. Background

Landfill 4 is also an industrial refuse dump on the Air Force IRP list that is located in the southwestern portion of Tinker AFB. Borings completed during initial closure studies in 1989 identified a sludge disposal area in the landfill. Soil gas surveys of Landfill 4 were performed in 1990 (9). The shallow gas results showed that the sludge dump contained high concentrations of VC, methane, and petroleum hydrocarbons. Landfill 4 possess an upper groundwater bearing zone that tends to saturate the waste, increasing the potential for spreading of groundwater contamination. To investigate the nature and extent of the sludge dump further, Tinker AFB requested that the area be addressed using CPT during the DT&E.

The study area for Landfill 4 is presented in Figure 55. Sludge Dump L4-2 was discovered during a 1987 boring investigation. Chemical analyses of the water sample from Well L4-2 found high VOCs (acetone, 2-butanone, 2-chloroethyl vinyl ether, and ethyl benzene) and metals (arsenic, barium, chromium, lead, mercury, and zinc). Resampling of the well in 1989 indicated a significant lowering in concentration of all contaminants, possibly due to aeration within the piezometer.

2. Approach and Results

Landfill 4 was investigated in a manner similar to Landfill 2, except no LIF profiling was performed. Fourteen (14) CPT push sites were completed in one day, at locations shown in Figure 55. The average depth to the "soft" refusal was 11 feet. A maximum depth of 15.6 feet was penetrated at LF4-06. Extremely soft materials were encountered at LF4-01 and 03 (Figure 56), indicating very loose and typically wet materials. The penetrations at LF4-02 (Figure 57) and 04 showed soft materials leading to a postulation that the zone containing these stations is comprised of sludge materials. An additional soft zone may exist around LF4-08 and LF4-09 as again soft materials were present in these CPT profiles.

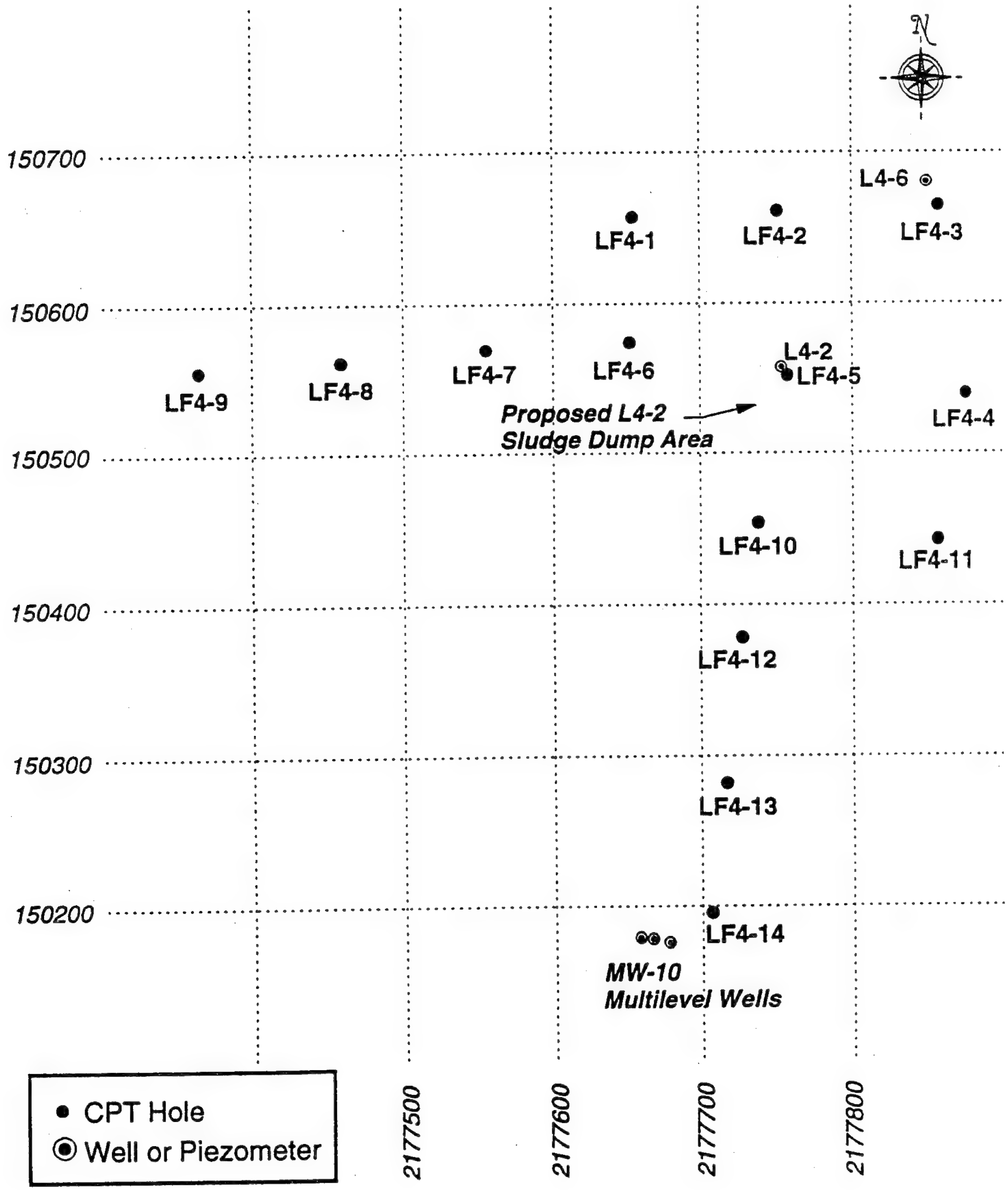


Figure 55. Site Map of the Area Investigated at Landfill No. 4.

LF4-03 09/26/92

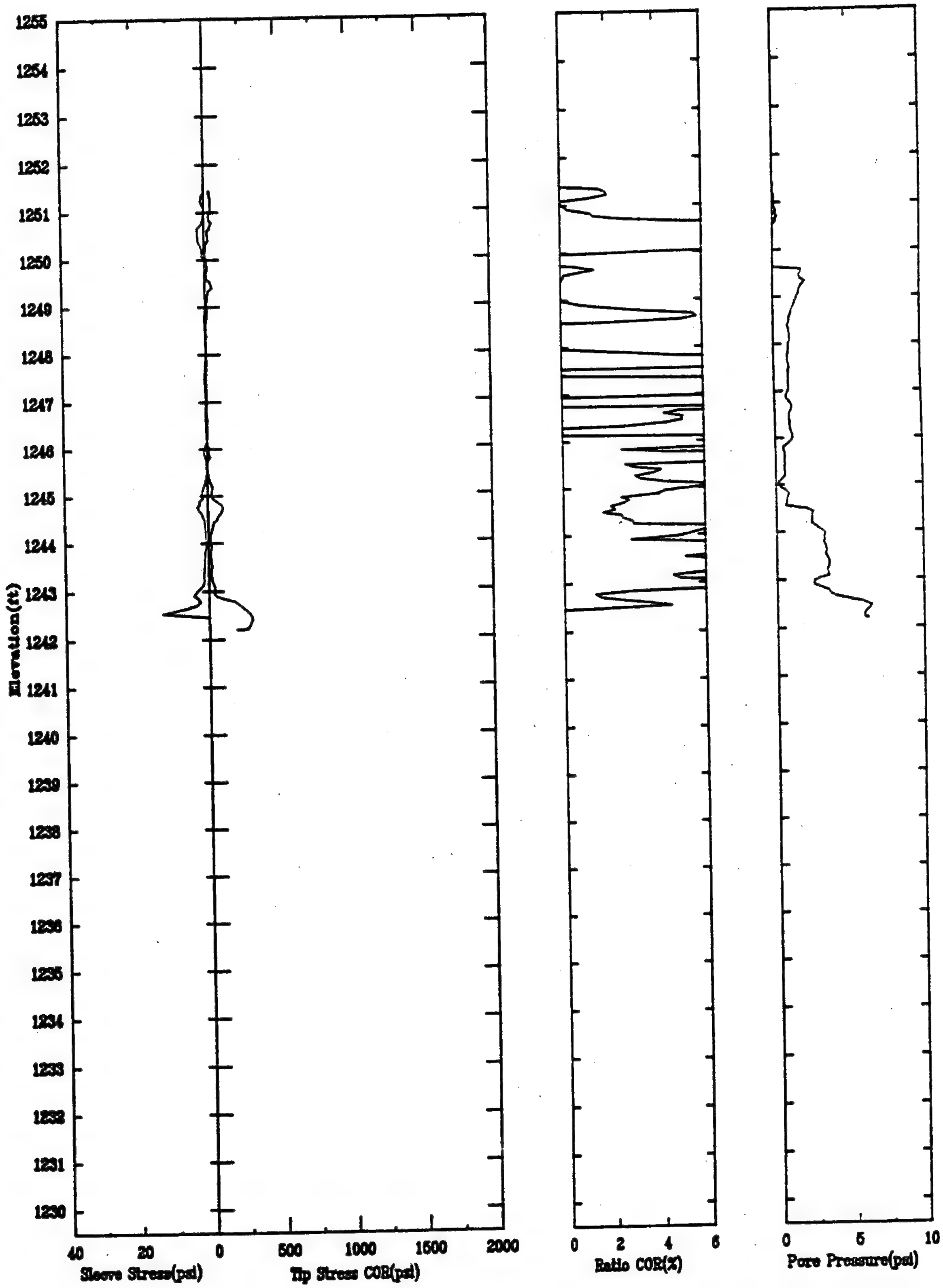


Figure 56. CPT Penetration Profile from LF4-03 Showing Extremely Soft, Wet Materials.

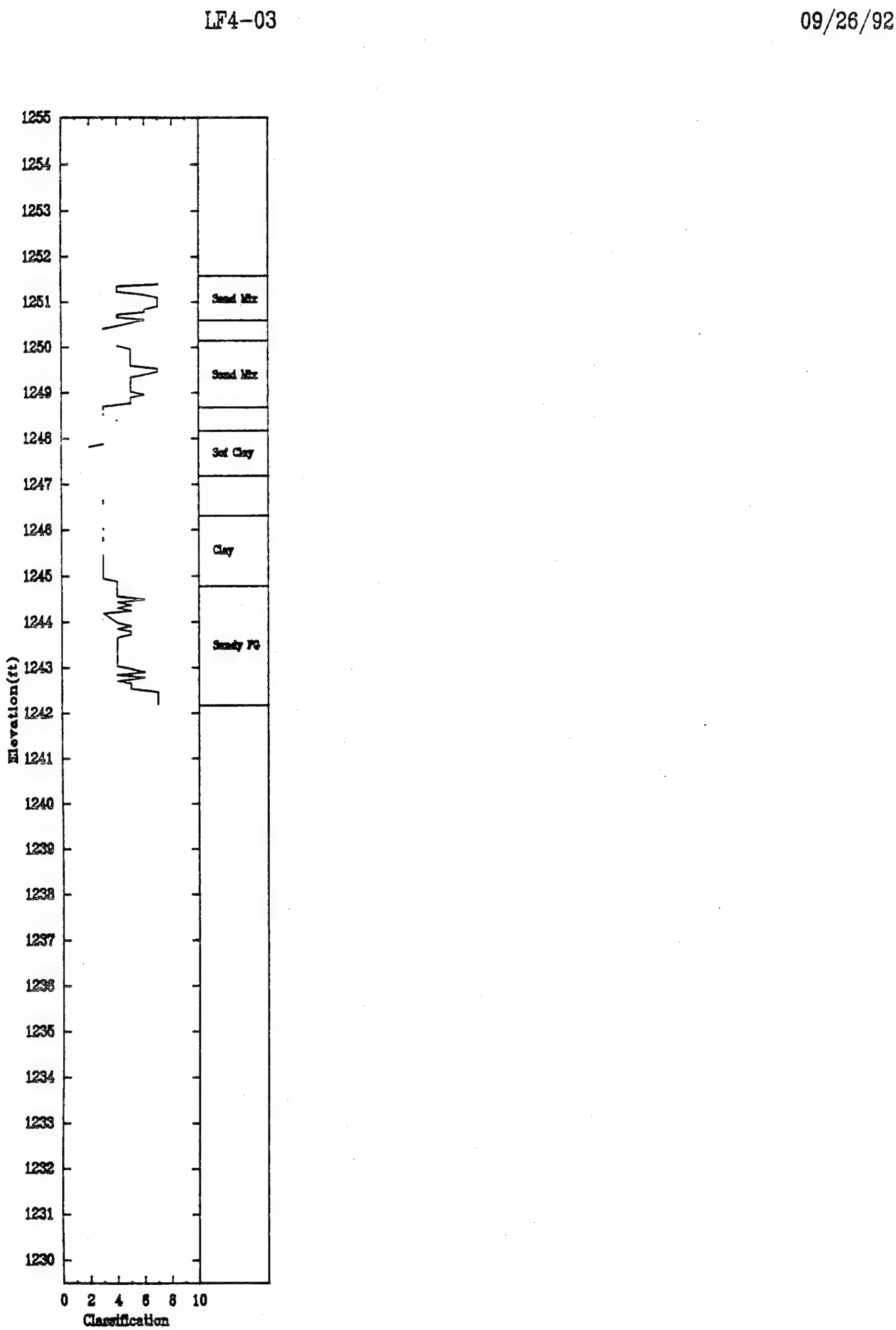


Figure 56. CPT Penetration Profile from LF4-03 Showing Extremely Soft, Wet Materials (Concluded).

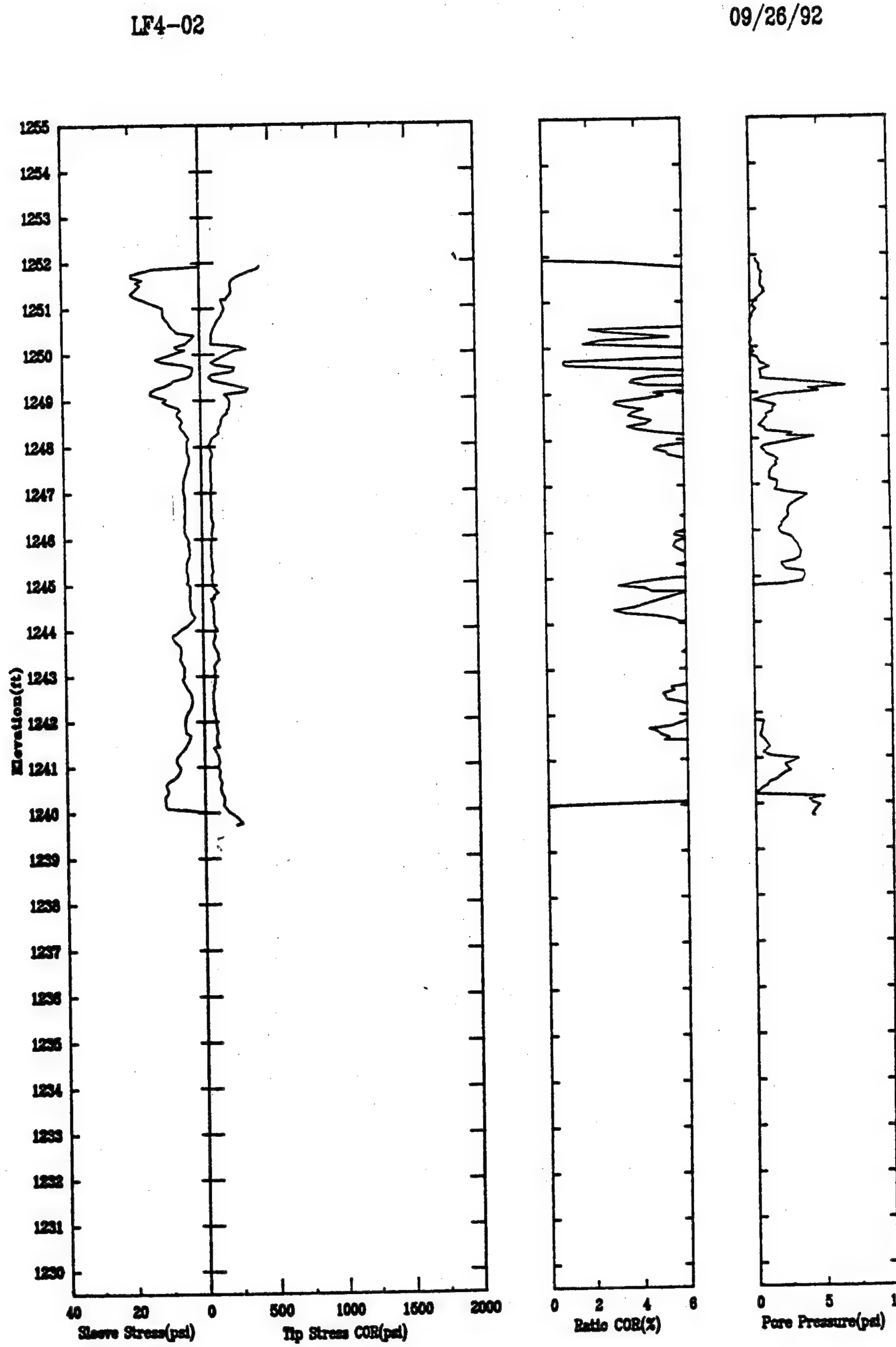


Figure 57. CPT Profile from LF4-02 Showing Soft, Potentially Sludge Type Materials.

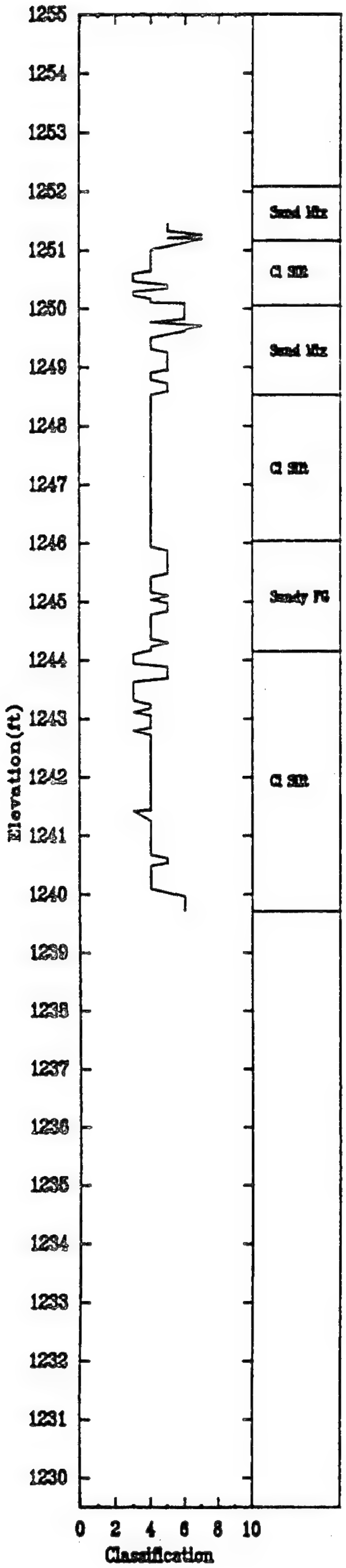


Figure 57. CPT Profile from LF4-02 Showing Soft, Potentially Sludge Type Materials (Concluded).

The penetration profiles from stations LF4-05 (Figure 58), 06, 07, 10, 11, and 13 all indicated refuse type materials. This was confirmed by CPT sampling at locations LF4-05, 06, and 10. Solid waste in a sandy clay matrix was generally recovered at these sites. Plastics, paper, cardboard, Kevlar® and gauze were some of the debris extracted; a strong putrid odor accompanied the waste.

The pore pressure measurements made with the CPT indicate that the groundwater table slopes from east to west, with the groundwater table at elevation of approximately 1253 feet at LF4-05, and elevation 1245 feet at LF4-09. In the north-south direction, the groundwater table is fairly stable in that locations LF4-10, 12, and 13 had groundwater elevations of 1250, 1247 and 1247 feet respectively. At LF4-14, near MW-10, the groundwater table appears to have risen to an elevation of 1250 feet again.

Chemical analyses of LF4 solids were made for VOCs, PAHs, and metals as presented in Tables 25 through 28. Station LF4-06 material, mainly composed of paper products, was very high in TPH (1 percent), various PAHs (25 mg/kg total 8270 base/neutral compounds), 0.140 mg/l chlorobenzene and trace amounts of ethyl benzene and xylenes. High TPH was found at LF4-05 as well. Table 27 provides a summary of the metals from the site; arsenic, barium, cadmium, chromium, lead and zinc were found to be significantly higher than background values.

Water samples were retrieved at CPT stations LF4-05 and 06 and tested for VOCs. Numer ous BTEX and chlorinated hydrocarbons were detected, the largest being toluene (3,400 ug/l) and trichloroethene (200 ug/l). Similar parameters were found in soil, water and soil gas performed in prior investigations at the site.

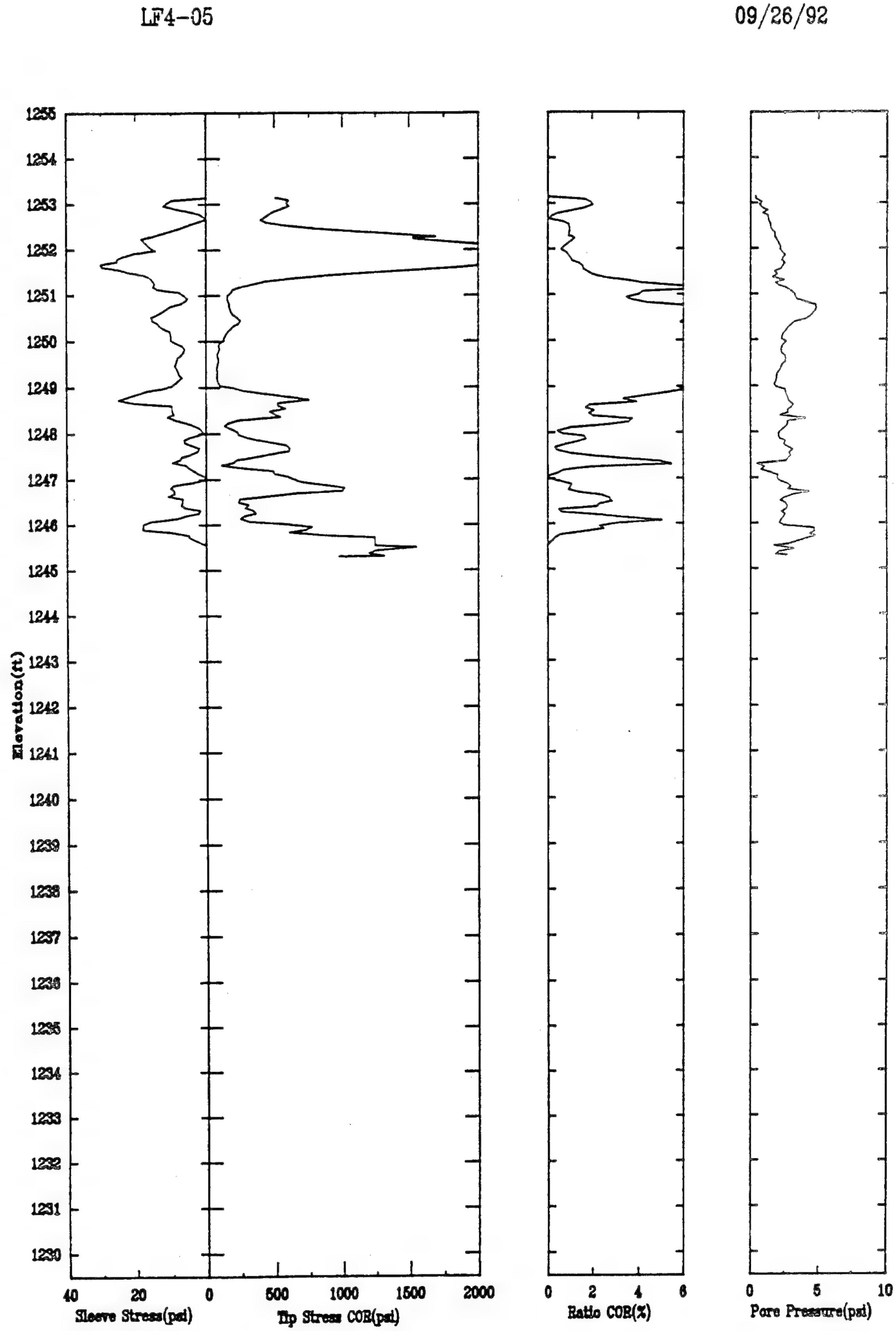


Figure 58. CPT Profile from LF4-05 Indicating Refuse Type Materials During the Penetration.

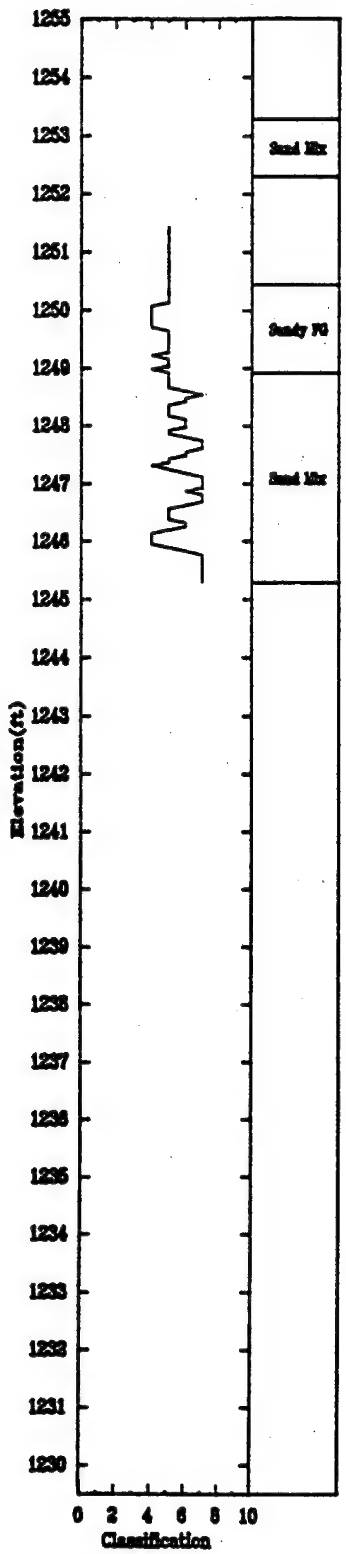


Figure 58. CPT Profile from LF4-05 Indicating Refuse Type Materials During the Penetration (Concluded).

TABLE 25. ONSITE ANALYSIS OF SOIL SAMPLES FROM LANDFILL NO. 4.

Soil Samples

Location		LF4-05	LF4-06	LF4-06	LF4-06	LF4-06	LF4-10
Depth Interval From	ft	3	2	8	13	12	8
To	ft	4.6	3.6	9.6	14.6	13	9.6
Methylene Chloride	(mg/kg)	0.040	0.046	0.041	0.043	0.043	0.045
1,1 Dichloroethene	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,1,1 Trichloroethane	(mg/kg)	0.126	0.022	<0.020	<0.020	<0.020	0.028
1,2 Dichloroethane	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Trichloroethylene	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020

TABLE 26. ONSITE ANALYSIS OF WATER SAMPLES FROM LANDFILL NO. 4.

Water Samples

Location		LF4-05WS	LF4-06WS
Depth below ground surface,	ft	8	14.5
Methylene Chloride	(ug/L)	248.364	< 4.0
1,1 Dichloroethene	(ug/L)	20.973	6.272
1,1,1 Trichloroethane	(ug/L)	< 4.0	< 4.0
1,2 Dichloroethane	(ug/L)	23.225	< 4.0
Trichloroethylene	(ug/L)	101.701	< 4.0

TABLE 27. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM LANDFILL NO. 4.

Soil samples

Location		LF4-05	LF4-06	LF4-06	LF4-10
Depth Interval From	ft	3	2	13	8
To	ft	4.6	9.6	14.6	9.6
Date Sampled		10/1/92	10/1/92	10/1/92	10/1/92
Total Petroleum Hydrocarbon	mg/kg	8000	11000	N/A	54
Benzene	mg/kg	<0.005	<0.005	<0.005	<0.005
Toluene	mg/kg	<0.005	<0.005	<0.005	<0.005
Ethyl Benzene	mg/kg	<0.005	0.08	<0.005	<0.005
Xylenes	mg/kg	<0.010	0.15	<0.010	<0.010
Total Phenols	mg/kg	<5	<5	<5	<5
Chlorobenzene	mg/kg	<0.005	0.14	<0.005	<0.005
1,1,2,2-Tetrachloroethane	mg/kg	<0.005	<0.005	<0.005	<0.005
Tetrachloroethene	mg/kg	<0.005	<0.005	<0.005	<0.005
Trichloroethene	mg/kg	<0.005	<0.005	<0.005	<0.005
trans-1,2-Dichloroethene	mg/kg	<0.005	<0.005	<0.005	<0.005
1,2-Dichloroethane	mg/kg	<0.005	<0.005	<0.005	<0.005
1,1-Dichloroethene	mg/kg	<0.005	<0.005	<0.005	<0.005
1,1,1-Trichloroethane	mg/kg	<0.005	<0.005	<0.005	<0.005
1,1,2-Trichloroethane	mg/kg	<0.005	<0.005	<0.005	<0.005
Methylene Chloride	mg/kg	<0.005	<0.005	<0.005	<0.005
Total Arsenic	mg/kg	72	<1.0	<1.0	<1.0
Total Barium	mg/kg	360	380	630	640
Total Cadmium	mg/kg	47	17	2.4	25
Total Chromium	mg/kg	57	48	38	200
Total Mercury	mg/kg	0.2	0.1	<.001	<.001
Total Nickel	mg/kg	42	38	29	41
Total Lead	mg/kg	1400	340	8.1	23
Total Zinc	mg/kg	310	380	54	40
Benzo(a)anthracene	mg/kg	<.33	3.4	N/A	<.33
Benzo(a)pyrene	mg/kg	<.33	2.2	N/A	<.33
Benzo(b)fluoranthene	mg/kg	<.33	8.3	N/A	<.33
Benzo(k)fluoranthene	mg/kg	<.33	1	N/A	<.33
Chrysene	mg/kg	<.33	5.8	N/A	<.33
Fluoranthene	mg/kg	<.33	0.93	N/A	<.33
Phenanthrene	mg/kg	<.33	2.1	N/A	<.33
Pyrene	mg/kg	<.33	2.5	N/A	<.33

TABLE 28. OFF-SITE ANALYSIS OF WATER SAMPLES FROM LANDFILL NO. 4.

Water Samples

Location		LF4-05	LF4-06	LF4-06
Depth, below ground surface	ft	9	4	15.5
Date Sampled		10/1/92	10/1/92	10/1/92
Benzene	ug/l	110	<5	<5
Toluene	ug/l	3400	<5	<5
Ethyl Benzene	ug/l	230	110	160
Xylenes	ug/l	570	170	<5
Chlorobenzene	ug/l	<5	50	15
Bromoform	ug/l	37	<5	<5
Tetrachloroethene	ug/l	35	<5	<5
Trichloroethene	ug/l	200	<5	<5
trans-1,2-Dichloroethene	ug/l	220	<5	<5
1,2-Dichloroethane	ug/l	21	<5	<5
1,1 Dichloroethane	ug/l	17	<5	<5
1,1 Dichloroethene	ug/l	<5	<5	<5
1,1,1-Trichloroethane	ug/l	<5	<5	<5
1,1,2-Trichlorethane	ug/l	<5	<5	<5
Methylene Chloride	ug/l	<5	<5	<5

I. OFFBASE PLUME DIFFERENTIATION

1. Background

The offbase site consists of property acquired by the Air Force. The land abuts Tinker AFB and is located northeast of Building 3001. The site of concern is located on the former Breeden Paint shop and the former Bonnewell residence (Figure 59). The Bonnewell and Testerman domestic wells have VC contamination. The objective of the DT&E investigation is to determine if near surface sources are responsible for the VOCs. Possible sources include dry wells and septic systems. The past history of Breeden Paint included the use of some solvents, so that the investigation focussed on that particular lot.

2. Approach and Results

As estimated in the statement of work, the refusal depths at the two CPT stations were 7.7 and 7.3 feet, respectively, showing a very flat surface for the refusal layer. Similar to the other test areas, the residual soil was sandy clay as indicated by the penetration of OFB-03 (Figure 60). Two borings completed just north of the abandoned leachfield for Breed Paint indicate that the refusal was on a silty fine sand unit, a weathered byproduct of sandstone. Drilling was progressed to 23 feet for sampling purposes. Water levels recorded in the open boreholes was approximately 6 feet, significantly shallower than the statement of work estimate of 15 feet. This water table measurement is also confirmed by the CPT pore pressure measurement from OFB-04.

Soil samples were taken every 3 to 7 feet from cores obtained from OFB-B01 and OFB-B02 along with CPT sampling at both OFB-03 and 04. These samples were analyzed for volatile, semivolatiles, and metals. The field GC (Table 29) indicated methylene chloride and 1,1,1 trichloroethane; however, duplicate samples using the GC/MS did not reproduce the results (Table 30). The GC/MS did indicate trace amounts of toluene and xylenes within the upper 7 feet. No semivolatiles were detected. Arsenic and barium were measured to have higher than normal values. Barium tended to be highest in the upper 10 feet of soil.

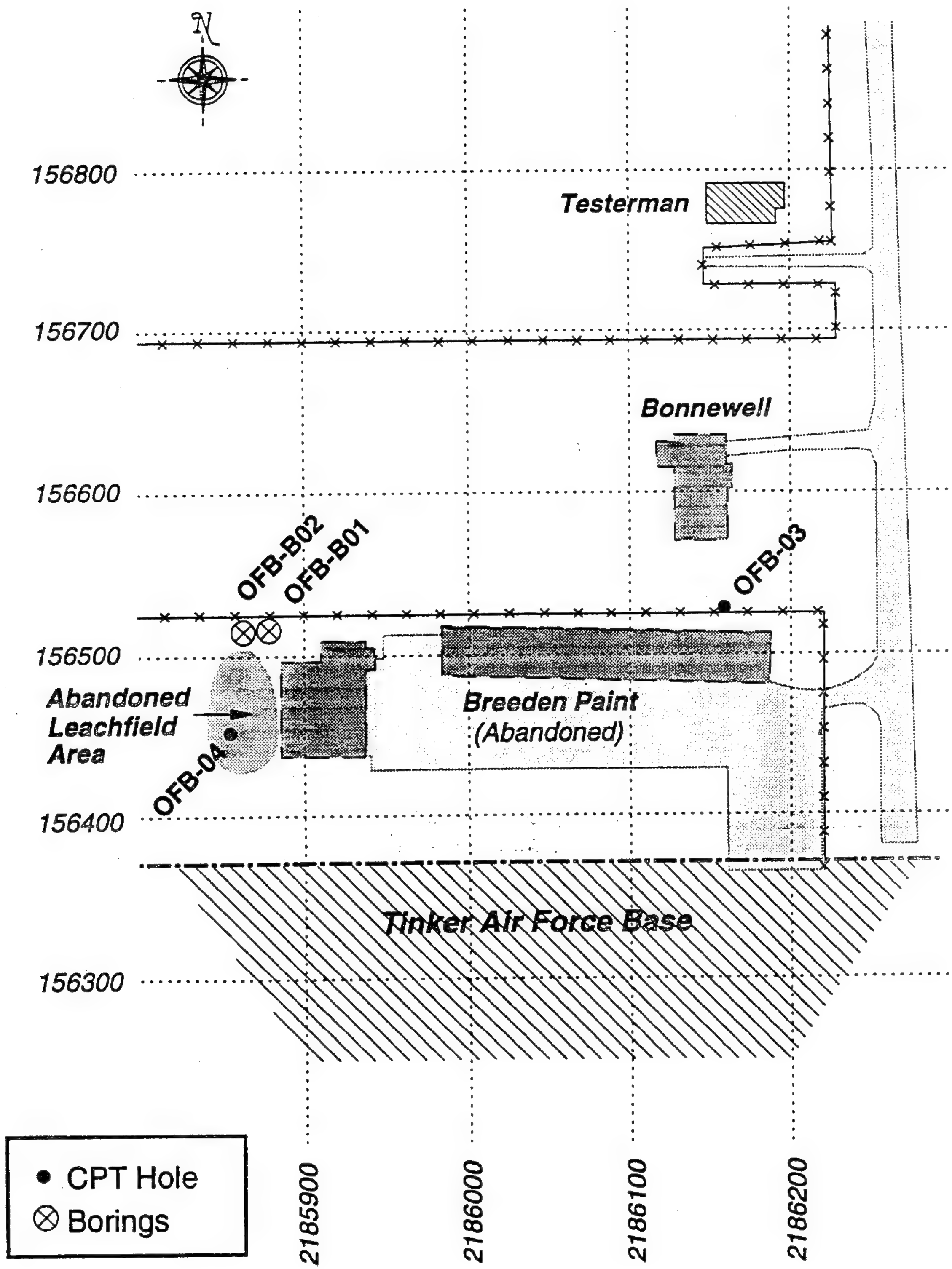


Figure 59. Site Map of the Offbase (Bonnewell) Area Showing the Breeden Paint Shop.

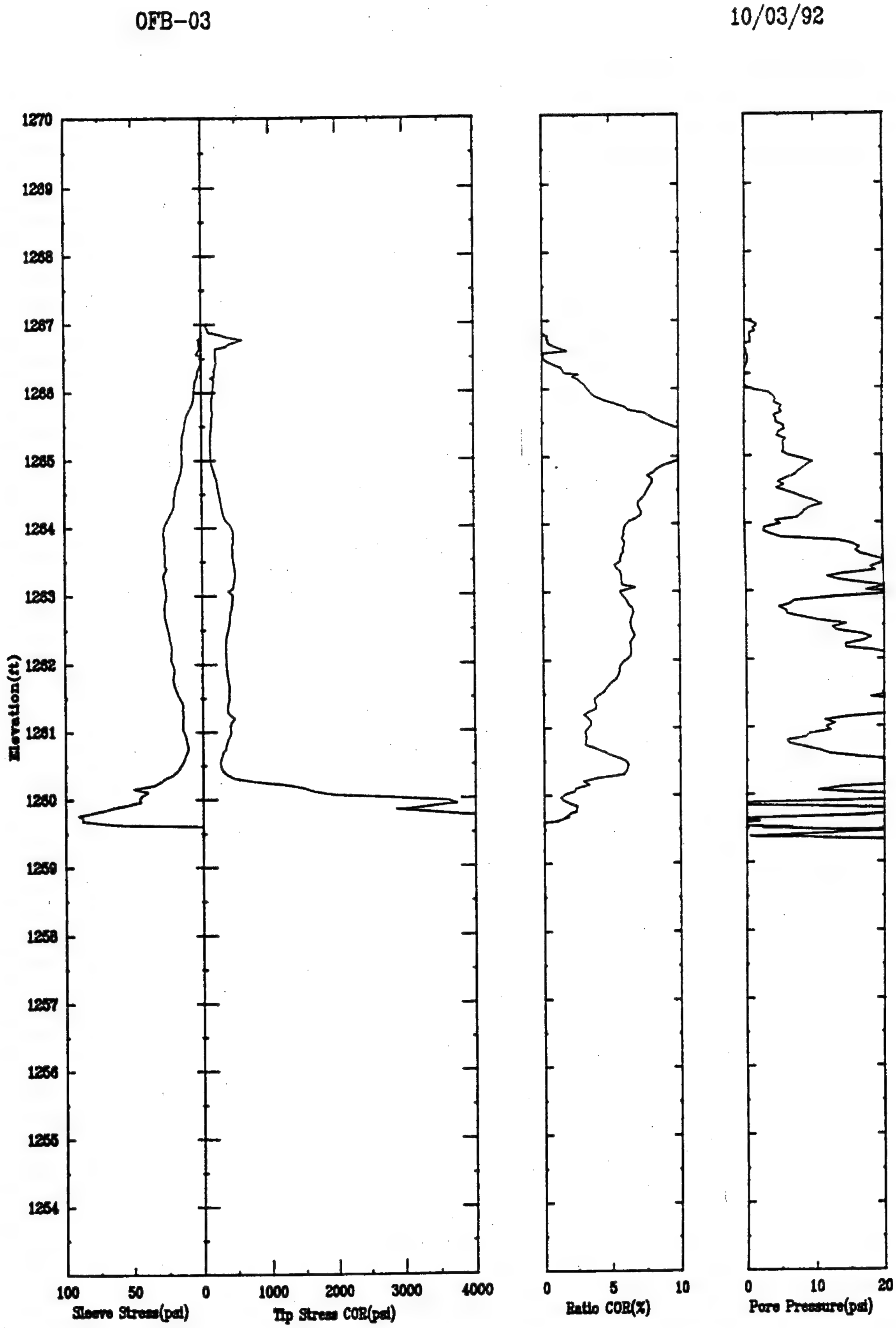


Figure 60. CPT Penetration Profile from OFB-03 Showing Typical Silty Sands.

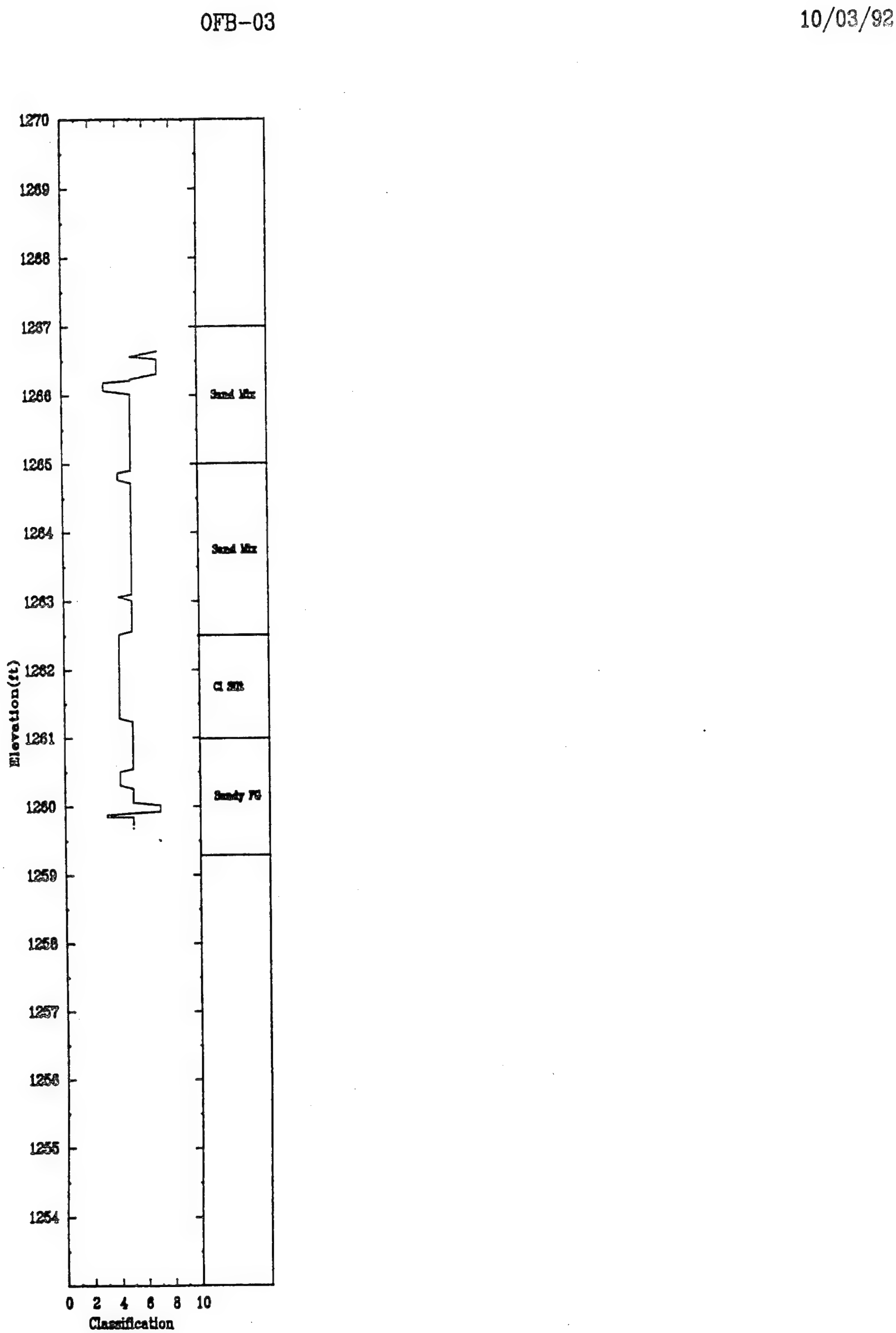


Figure 60. CPT Penetration Profile from OFB-03 Showing Typical Silty Sands (Concluded).

TABLE 29. ONSITE ANALYSIS OF SOIL SAMPLES FROM THE OFF-BASE AREA.

Soil Samples

Location		OFB-03	OFB-04	OFB-04	OFB-B01	OFB-B01	OFB-B01	OFB-B01	OFB-B02	OFB-B02	OFB-B02	OFB-B02
Depth Interval From	ft	5	4	5.6	6	9	16	21	7	11	16	22
To	ft	6.7	5.6	7.4	7	10	17	22	8	12	17	23
Methylene Chloride	(mg/kg)	0.041	0.043	<0.020	0.091	0.117	0.066	0.053	0.084	0.046	0.090	0.029
1,1 Dichloroethene	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
1,1,1 Trichloroethane	(mg/kg)	0.030	0.031	<0.020	0.023	0.050	0.027	<0.020	0.036	<0.020	0.044	<0.020
1,2 Dichloroethane	(mg/kg)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Trichloroethylene	(mg/kg)	<0.020	<0.020	0.000	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020

TABLE 30. OFF-SITE ANALYSIS OF SOIL SAMPLES FROM THE OFF-BASE AREA.

Soil Samples

Location		OFB-B01	OFB-B01	OFB-B01	OFB-B01	OFB-B02	OFB-B02	OFB-03	OFB-04	OFB-04
Depth Interval From	ft	6	9	16	21	11	22	5	4	5.6
To	ft	7	10	17	22	12	23	6.7	5.6	7.4
Date Sampled		9/28/92	9/28/92	9/28/92	9/28/92	9/28/92	9/28/92	10/3/92	10/3/92	10/3/92
Total Petroleum Hydrocarbon	mg/kg	N/A	N/A	N/A	N/A	N/A	N/A	56	19	29
Benzene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
Toluene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	0.034	N/A	0.017
Ethyl Benzene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
Xylenes	mg/kg	N/A	N/A	<0.010	N/A	N/A	<0.010	0.016	N/A	<0.010
Semi-Volatiles (8270)*	mg/kg	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Phenols	mg/kg	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chlorobenzene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
1,1,2,2-Tetrachloroethane	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
Tetrachloroethene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
Trichloroethene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
trans-1,2-Dichloroethene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
1,2-Dichloroethane	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
1,1-Dichloroethene	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
1,1,1-Trichloroethane	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
1,1,2-Trichloroethane	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
Methylene Chloride	mg/kg	N/A	N/A	<0.005	N/A	N/A	<0.005	<0.005	N/A	<0.005
Total Arsenic	mg/kg	2	<1	13	1	3	<1	1	<1	<1
Total Barium	mg/kg	220	1200	74	16	290	51	240	130	140
Total Cadmium	mg/kg	3	4	5	1	5.3	3	1.5	0.98	1.6
Total Chromium	mg/kg	5.6	30	23	8	19	12	23	16	16
Total Mercury	mg/kg	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.001	<0.001	<0.001
Total Nickel	mg/kg	8.6	23	19	5.8	14	10	14	8.5	7.4
Total Lead	mg/kg	3	3	3	<1	6.4	2	3.2	8.4	2
Total Zinc	mg/kg	15	28	29	8.1	21	13	20	22	12

* Refer to lab reports for parameters and detection limits

While the results did not produce significant quantities of chlorinated solvents, the presence of other aromatics and some possible paint-related metals (barium) were found. Based on the probable past property usage, small quantities of hazardous waste may have been disposed so that soil contamination resulted.

SECTION V

SUMMARY AND CONCLUSIONS

During the thirty day demonstration program performed at Tinker, AFB, a total of 112 Laser Induced Fluorescence (LIF) Cone Penetrometer profiles (CPT) were conducted at eight individual test areas, including a background area. The profiles were conducted to determine soil stratigraphy, groundwater mapping, and the presence or absence of petroleum based contamination. In addition to the LIF-CPT profiling which provided the majority of the site characterization data, conventional drilling, CPT soil sampling, and groundwater sampling were used to obtain samples for contamination confirmation. Analytical testing was performed both in the field using a mobil gas chromatography laboratory and by ANALAB Corp. in Kilgore, Texas.

All the various data forms were brought together in the field to make real time decisions concerning site characterization operations. To assist in the characterization of several of the sites, a three-dimensional site characterization package developed by ARA was used to visualize data obtained and locate where additional data was needed. This represents the first time adaptive site characterization with scientific visualization has been performed in the field by a private contractor. By using the LIF-CPT along with field analytical testing and scientific visualization, sites were able to be characterized in a single operation, representing a significant cost and time savings. Using conventional methods, only one of the seven sites could have been characterized during the thirty day demonstration.

In summary, the thirty-day LIF-CPT field testing program demonstrated the advantages of the AFSCAPS system including:

1. That the CPT is minimally invasive and generates no drilling waste.
2. That the CPT is a rapid test and greatly reduces cost.
3. That continuous profiling of soil stratigraphy and contamination can be made in which even the thinnest soil layers can be detected. For many sites, thin sand seams carry the majority of the contaminants and are difficult to locate with conventional drilling techniques.

4. That field gas chromatography can be used to significantly reduce sample turn-around time and provide confirmation of the results indicated by the LIF-CPT.
5. That real time determination of soil stratigraphy, water table depth and degree of contamination can be made with the LIF-CPT. This data can be combined with other data to optimize location of the next sounding. On full-scale investigations, this capability can greatly reduce the time required to characterize a site, and result in a more thorough site investigation.
6. That three-dimensional scientific visualization can be performed in the field. This visualization process is valuable for rapidly assess the high volume of data that is obtained and presenting the problem in a form that both engineers and managers can easily understand. This allows rapid, intelligent decisions to be made concerning the location of the next LIF-CPT sounding, the location of samples such that unnecessary sampling does not occur, and the location of monitoring well for long-term analysis.

REFERENCES

1. Mankin, C.J., Expert Witness Testimony Submitted to U.S. Senate Subcommittee on Environment, Energy and Natural Resources, December, 1984.

2. American Society for Testing and Materials, "Standard Method for Deep Quazi-Static, Cone and Friction-Cone Penetration Tests of Soil," ASTM Designation: D3441, 1986.

3. Robertson, P.K., and R.G. Campanella, "Guidelines for Using the CPT, CPTU, and Marchetti DMT for Geotechnical Design: Vol. II - Using CPT and CPTU Data," Civil Engineering Dept., University of British Columbia, March 1988.

4. Timian, D.A., W.L. Bratton, B.E. Fisk, Piezo Electric Cone Penetration Tests in Support of Geotechnical Investigations at Sections 6/7 and 1/9 of Fresh Kills Landfill, Staten Island, New York - Development of Correlations for Soil Classification and In-Situ Properties, ARA, Inc. Contract No. 5693, May, 1992.

5. Sample Analysis for Tinker Air Force Base. Sample #10006031 Obtained September 16, 1991 from Monitoring Well in North Tank Area. Tested September 17, 1991 by USPCI - Remedial Services, Oklahoma City, OK.

6. Records Search Performed by Engineering Science of Tinker Air Force Base, April, 1992.

7. U.S. Army Corps of Engineers, "Building 3001 Remedial Investigations, Tinker Air Force Base, Installation Restoration Program," unpublished Multi-Volume Report, January, 1988.

8. U.S. Army Corps of Engineers, "Shallow Soil Gas Investigation Landfills #2 & 4, Tinker Air Force Base," May, 1990.